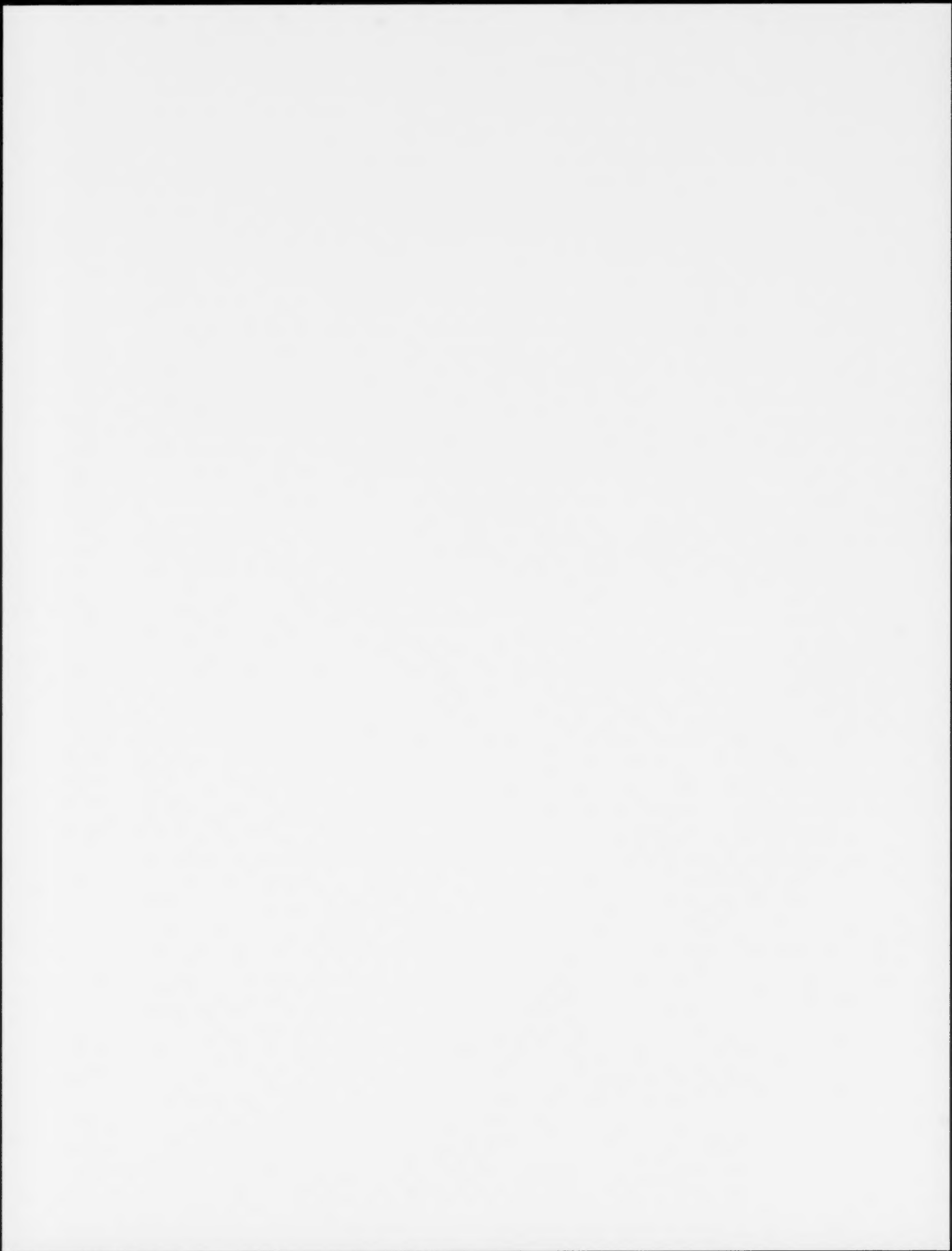


Understorey Vegetation Response following Restoration of Ingrown Ponderosa Pine and Douglas-fir Stands in the East Kootenay Region

2012





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R.F. Newman, J. Parminter, and B.M. Wallace



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ABSTRACT

The response of understorey vegetation was monitored over a 7-year period following restoration of ingrown stands of ponderosa pine (*Pinus ponderosa*) and interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) in the East Kootenay region of British Columbia. The restoration was based on a prescription of partial cutting and slashing in 1999 and 2000. The ponderosa pine site was also subjected to a prescribed fire in April 2004. At the ponderosa pine site, total herbaceous biomass doubled over a 6-year period on areas where treatments increased understorey light by 32–44%. Most of the forage increase was due to grass biomass, including pinegrass (*Calamagrostis rubescens*) and bunchgrasses. The forage response developed over time after an initial lag of 2–4 years and was most evident by years 5 and 6 following treatment. A regression model derived from 2006 herbaceous biomass/light relationships at the ponderosa pine site predicted that 80% canopy removal is required to achieve 50% of the forage potential for the site. Despite an increase in herbaceous biomass, the frequency of most plant species was not different on more open canopy areas compared to those with a relatively more closed canopy. This indicates that little colonization of unvegetated areas occurred during the study period. In fact, increases in the frequency of exposed mineral soil, especially following the prescribed fire, indicate that more unvegetated areas were created. The prescribed fire increased the frequency of exposed mineral soil by 40% and initially reduced the frequency of five important understorey plant species. At the Douglas-fir site, restoration treatments that created an average of 32% more understorey light increased total herbaceous biomass by 70% after 7 years. Most of the forage increase was due to forb biomass. The total forage response developed steadily over time after an initial lag of 2–4 years. The same lag in response was noted at the ponderosa pine site and was likely due to the same reasons (i.e., mechanical damage due to harvesting, and drought). It is evident at both sites that desirable plant species such as rough fescue (*Festuca campestris*) have not yet been able to reproduce substantially with the treatments employed and under the environmental conditions experienced over the study period.

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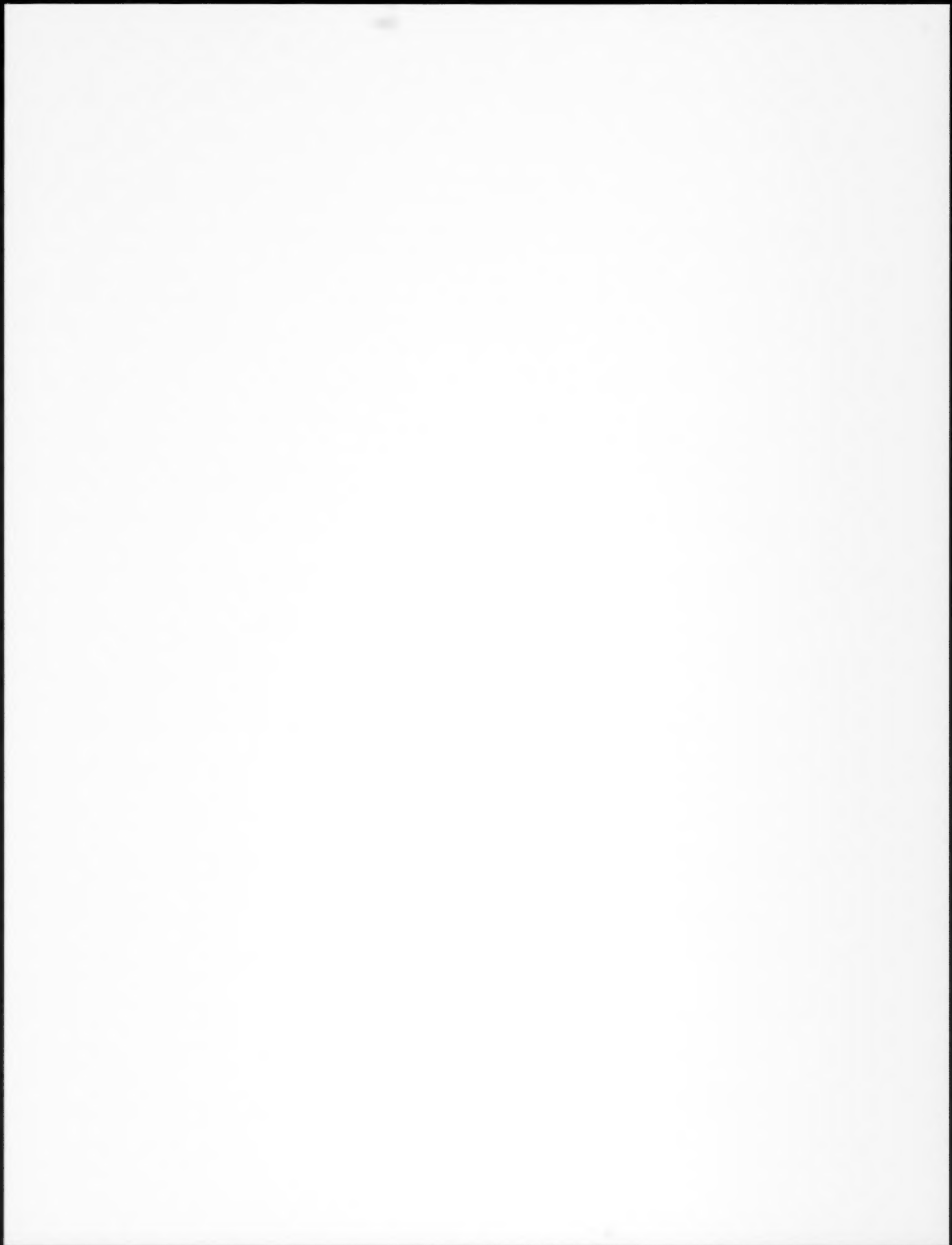
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Dry forests of ponderosa pine (*Pinus ponderosa*) and interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) occur at low to mid elevations along the valleys within the southern interior of British Columbia. In the East Kootenay region, grassland and dry open forests occur in a mosaic with dense forests. The grassland and open forests are thought to have developed as a result of frequent lightning-caused fire and burning by Aboriginal peoples in pre-European times (Daigle 1996; Wikeem and Ross 2002; Hall 2008) in combination with suitable edaphic and topographic conditions. Other authors believe that a widespread low-severity fire regime was very unlikely in the East Kootenay region, and that a mixed-severity disturbance regime was more probable (Klenner et al. 2008). In the early 1900s, logging and subsequent fires fuelled by logging debris contributed to opening up large areas (Wikeem and Ross 2002). Since the 1940s, fire in the dry forests has become less frequent, possibly due to factors such as climate change, effective fire suppression, livestock grazing, and cessation of burning by First Nations peoples (Wong et al. 2004).

The East Kootenay region of British Columbia is unique among dry southern interior forests because of the concentration of wild ungulates, such as white-tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), and elk (*Cervus canadensis*), and it contains important ungulate wintering areas (Simpson 1988; Jamieson and Hebert 1993). Competition among wild ungulates and cattle for the forage resource in this region was first documented in the mid-1900s (Wikeem and Ross 2002) and has continued into the 2000s. Exacerbating this conflict is the fact that an estimated 1500–3000 ha of open forest and grassland are lost annually to tree ingrowth and forest encroachment in the East Kootenay region (Gayton 1997). Fire suppression, livestock grazing, and selective logging are believed to have contributed to forest encroachment on grasslands and ingrowth within open forest (Gray et al. 2004). Ingrowth often results in the loss of shade-intolerant understorey plant communities, the reduction of understorey herbaceous biomass, the loss of habitat for wildlife species that rely on open conditions, and an increased risk of catastrophic wildfire.

In response to concerns about catastrophic wildfire and loss of open forest conditions in East Kootenay forests, a program was initiated in 1996 to restore open forest conditions in key areas (Rocky Mountain Trench Ecosystem Restoration Steering Committee 2006; Harris 2011). The program strategy is based on the Kootenay/Boundary Land Use Plan Implementation Strategy (Province of British Columbia 1997), which identified 250 000 ha of Crown land in the East Kootenay region as previously fire-maintained. The plan prescribes 118 500 ha, about 47% of the fire-maintained ecosystems in the region, for restoration by 2030. The restoration prescription usually begins with a harvest pass to remove merchantable trees and reduce overstorey tree density to between 76 and 400 stems per hectare. Slashing is used to eliminate excess non-merchantable, intermediate-layer trees that cannot be safely removed in a prescribed fire (Province of British Columbia 1997). A prescribed fire follows within 5 years, with planned maintenance prescribed fires scheduled every 10–15 years thereafter (Harris 2011).

Land use plan targets have been established and restoration of ingrown stands is occurring despite a general lack of knowledge regarding the ability to achieve all restoration objectives. Target understorey plant communities have been defined, but an understanding of understorey plant succession following restoration treatments is required to achieve success. The objective of this project is to document the changes in the understorey plant community following partial cutting/slashing of two, and prescribed burning of one, ingrown dry forest stand. Page et al. (2005) documented the early development (1–2 yr) of the understorey in these stands and reported poor success in achieving increased herbaceous biomass and desirable plant species succession. We report herein on the results to year 6 and 7 from the same sites.

2 MATERIALS AND METHODS

2.1 Site Description

Two sites were selected along the east-facing slope of the Rocky Mountain Trench in the East Kootenay region 50 km north of Cranbrook, British Columbia. The ponderosa pine (48°50'32" N, 115°41'45" W) and Douglas-fir (49°59'13" N, 115°42'43" W) sites are 16 km apart and at 900 m elevation on flat to gently rolling topography. Soils are classified as Orthic Eutric Brunisols and are predominantly gravelly, sandy loams developed from fluvio-glacial parent material (Lacelle 1990). Mean monthly air temperatures vary from -8° to 18° C. Growing-season (April–October) precipitation averages 220 mm at the Johnson Lake fire weather station, with a clearly defined peak in June (Figure 1). The Johnson Lake fire weather station is located 7 km south of the Douglas-fir site and 9 km north of the ponderosa pine site at 50 m lower elevation (BCMFLNRO 2012a). The area is characterized by relatively short, mild winters, with approximately 150 cm of snow falling during the winter months. The sites provide valuable winter range for wild ungulates due to lower snow-fall compared to higher-elevation ecosystems (Simpson 1988; Jamieson and Hebert 1993). Point mean fire intervals of 14 and 19 years were estimated for two Kootenay Dry Mild Interior Douglas-fir variant (IDF_{dm2}) stands within 50 km of the sites (Gray et al. 2004).

Cattle grazing on the sites followed the tenure holders' operational prescriptions (Range Use Plans), which were approved by the British Columbia Ministry of Forests, Lands and Natural Resource Operations. The ponderosa pine site is located in the Wolf Pasture (678 ha), while the Douglas-fir site is located in the Pump Pasture (573 ha). Pastures were generally grazed for one month annually on a spring/fall rotation. The management practice on grass-land openings in these areas is to graze cattle at 2–4 hectares per animal unit month. Wild ungulates followed normal distribution patterns on all parts of the pastures they had access to during the study, but the exact number of deer and elk using each site was not documented.

The ponderosa pine site is classified as Kootenay Dry Hot Ponderosa Pine variant (PP_{dh2}) (Braumandl and Curran 1992; Lloyd et al. 2006). Before treatment, the dominant tree species were immature to mature ponderosa pine and Douglas-fir, interspersed with areas of 20- to 60-year-old lodgepole pine (*Pinus contorta*). Crown closure averaged 66%. The understorey was dominated by kinnikinnick (*Arctostaphylos uva-ursi*) and pinegrass (*Cal-*

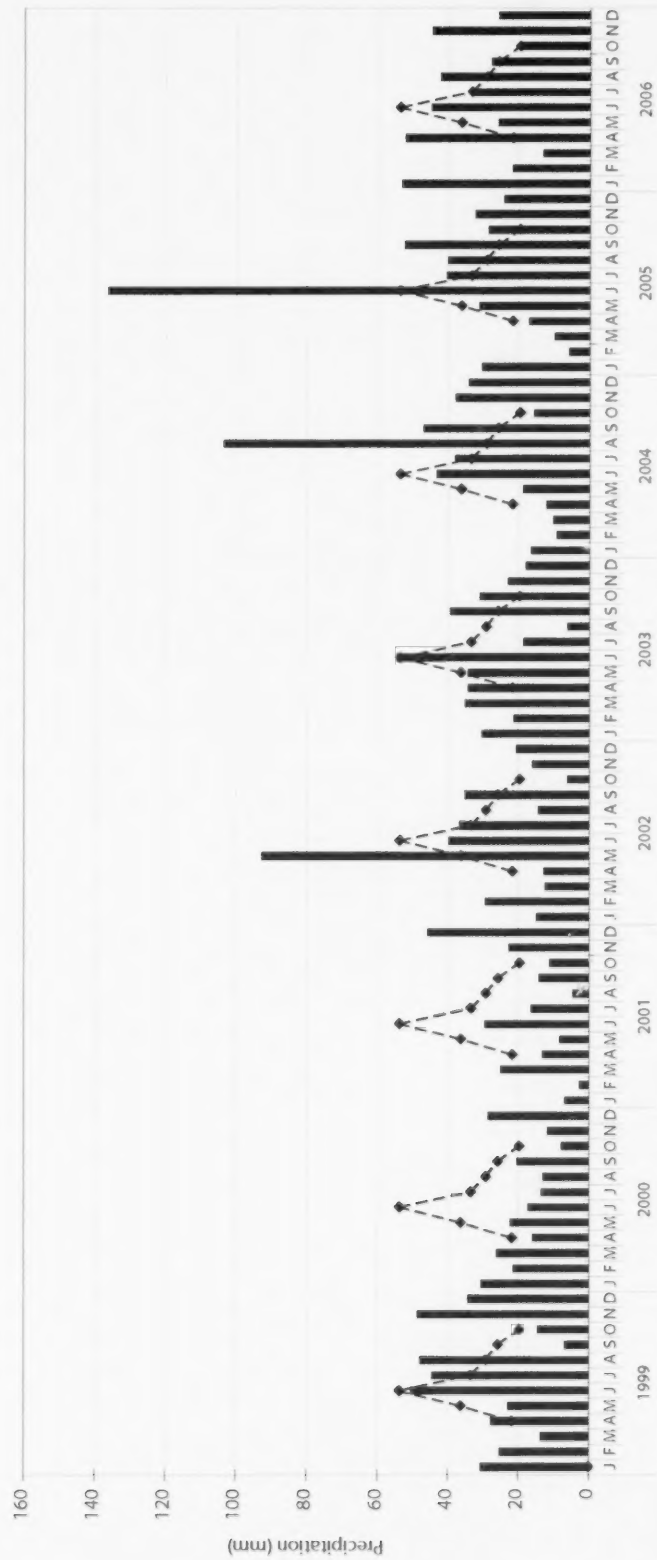


FIGURE 1 Monthly precipitation from 1999 to 2006 (bars) and 25-year normal April–October precipitation (dashed lines) at Johnson Lake fire weather station, near Skookumchuck, British Columbia.

magrostis rubescens), and included subordinate amounts of northwestern sedge (*Carex concinnoides*), rough fescue (*Festuca campestris*), and spreading needlegrass (*Achnatherum richardsonii*). Bluebunch wheatgrass (*Pseudoroegneria spicata*) occurred infrequently. Saskatoon (*Amelanchier alnifolia*) and antelope-brush (*Purshia tridentata*) were the most common shrubs.

The Douglas-fir site is classified as Kootenay Dry Mild Interior Douglas-fir variant. Before treatment, the dominant tree species were immature to mature Douglas-fir, ponderosa pine, and lodgepole pine in approximately equal volumes. Crown closure averaged 73%. The understorey was dominated by pinegrass, birch-leaved spirea (*Spiraea betulifolia*), and kinnikinnick, and included subordinate amounts of northwestern sedge, rough fescue, and bluebunch wheatgrass. Saskatoon and Douglas-fir saplings were common in the shrub layer.

2.2 Sampling and Assessment

Sampling for understorey herbaceous cover, litter, exposed mineral soil, microbiotic crust, shrub cover, forest floor organic material depth (LFH), and woody debris was completed at both sites prior to the partial-cut treatments in 1999. Sampling for herbaceous biomass was also completed at the ponderosa pine site in 1999. All sampling was conducted within 12 × 12-m macroplots and was arranged along three parallel 10-m long transects spaced 4 m apart. At each site, macroplots were selected before treatment from a 100 × 100-m grid of locations previously sampled for timber cruise purposes. Of these locations, only macroplots that met the following criteria were sampled:

1. classified as PPdh2 for the ponderosa pine site or IDFdm2 for the Douglas-fir site; and
2. slopes < 5%.

Eighteen randomly located macroplots were sampled at the ponderosa pine site; 14 randomly located macroplots were sampled at the Douglas-fir site. Sampling for post-treatment understorey herbaceous cover, litter, exposed mineral soil, microbiotic crust, shrub cover, LFH depth, and woody debris, and herbaceous biomass clipping were completed in 2000, 2001, 2003, 2004, 2005, and 2006 at both sites.

2.2.1 Understorey herbaceous cover Understorey herbaceous cover was determined using a modified Daubenmire canopy cover method (Daubenmire 1959). The canopy cover of each vascular plant species was recorded to the nearest percentage. All herbaceous vascular plant species within a 20 × 50-cm plot frame were identified to genus and species using the nomenclature of Douglas et al. (1998–2002). Cover assessments were also recorded for the following categories:

1. litter (standing or fallen material from previous growing seasons);
2. exposed mineral soil;
3. microbiotic crust (including lichen, algal crust, and bryophytes);
4. rocks (> 5 cm diameter); and
5. fecal material (cattle manure and wild ungulate pellets).

Twenty Daubenmire quadrats, systematically located every 1 m along two 10-m transects, were assessed at each macroplot at each site during July–August.

The values recorded for understorey herbaceous cover were used to calculate plant frequency of important species. Plant frequency is the number of times a plant species is present in a given number of quadrats (Society for Range Management 1989). It is calculated by summing the number of times a particular species occurs in the plots and expressing this sum as a percentage of the total plots available.

2.2.2 Shrub cover The canopy cover of shrubs and small trees (< 1.5 m tall) was assessed within 1 × 2-m quadrats. The cover of each shrub / small tree was recorded by exact percentage and was identified to genus and species. Twenty shrub / small tree quadrats were assessed annually at each macroplot at each site during July–August.

2.2.3 Herbaceous biomass Standing herbaceous vegetation was clipped to ground level within 1 × 0.5-m quadrats, and the litter (previous year's growth) was separated from the current year's growth. The current year's clipped material was sorted into the following groups:

1. bunchgrasses (bluebunch wheatgrass, rough fescue, Idaho fescue [*Festuca idahoensis*], spreading needlegrass, junegrass [*Koeleria macrantha*], needle-and-thread grass [*Hesperostipa comata*]);
2. pinegrass;
3. sedges (mostly northwestern sedge);
4. forbs (a mix of 30–40 species, each with usually < 2% cover); and
5. other grasses (all other non-bunchgrasses) (see Appendices A1 and A2 for complete species lists).

Clipping was completed at peak understorey vegetation development in September. Shrubs and trees were not clipped. Samples were air dried to minimize decomposition of the plant matter. Samples were oven-dried at 70°C to a constant weight, and were weighed to the nearest 0.1 g.

Quadrat locations were randomly located along a transect line, with the restriction that previously clipped locations could not be reused. At least one quadrat was clipped at each macroplot in every sampling year except 1999, when only nine macroplots were sampled at the ponderosa pine site. The average value per macroplot was used for data analysis when more than one quadrat was clipped at a macroplot.

Grazing use Grazing exclusion cages were established at each macroplot to determine grazing use by cattle and wild ungulates during May–September of 2004, 2005, and 2006. Cages were established during early May before cattle were turned out. Grazing use by overwintering wild ungulates (October–April) was therefore not determined. Cage locations were determined by ocularly matching the vegetation in the uncaged quadrats (paired plot design). Procedures previously described for herbaceous biomass clipping were employed on caged and uncaged areas. Grazing use was determined by calculating the percentage difference between herbaceous biomass clipped on caged versus uncaged areas.

2.2.4 Understorey light The ratio of diffuse non-interceptance (DIFN) light measured at a macroplot compared to DIFN light measured simultane-

ously at a point with an unobstructed sky view is a measure of light penetration into the canopy. The amount of DIFN light was recorded with two LI-COR LAI-2000 Plant Canopy Analyzers (Welles and Norman 1991). Previous studies have shown that DIFN light values measured by this sensor give unbiased estimates of average growing-season fractional transmittance (percentage of open-sky light) (Comeau et al. 1998; Gendron et al. 1998; Machado and Reich 1999).

Measurements were taken at the height of a Daubenmire frame (25 cm). Twenty light measurements were taken at each macroplot at each site. The positions corresponded to the locations used to sample vegetation cover. Understorey light was first sampled in 1999 before treatment and again in 2001 to determine changes due to the harvest treatment.

2.2.5 Overstorey stand characteristics Operational timber cruise data were used to quantify pre-treatment stand characteristics such as basal area, density, and volume (Keller 1997). Plots were re-cruised following partial cutting to quantify changes in stand structure.

2.2.6 Prescribed fire assessment

Fuel load Fuel load was assessed at each macroplot at the ponderosa pine site in 2003 (before prescribed fire) and 2004 (after prescribed fire) using the line intersect method (Trowbridge et al. 1989). Twenty metres of line intercept fuel load sampling were assessed at each macroplot.

Bark char height The maximum height of stem blackening due to the prescribed fire was measured at each macroplot at the ponderosa pine site in 2004 following the prescribed fire. The closest three mature trees to the macroplot centre were selected for measurement. Bark char height has been correlated with flame length and fire intensity (Alexander 1982; Beverly and Martell 2003), but was used in this study as a direct measure of fire effects.

Forest floor depth Forest floor depth was determined to the nearest 1 cm at 20 systematic locations along two transects. This was completed at each macroplot at the ponderosa pine site in 2003 (before prescribed fire) and 2004 (after prescribed fire).

2.3 Treatments

At the ponderosa pine site, restoration treatments were conducted using partial cutting and slashing in June–July 2000. Partial cutting consisted of thinning the forest canopy and removing intermediate layer trees. Ponderosa pine and Douglas-fir > 35 cm dbh were retained, while most lodgepole pine was removed. The partial-cutting harvest pass removed an average of 48 m³/ha of tree volume, leaving 27 m³/ha in the residual stand. Merchantable stem density decreased by 513 stems per hectare, leaving 192 stems per hectare on the site. Understorey light increased by an average of 30% following harvest. Slashing consisted of cutting pre-commercial, intermediate layers to reduce the risk of crown fire during prescribed understorey burns and to contribute to ground fuels.

The entire ponderosa pine site was subjected to a prescribed fire in April 2004 (Table 1). The prescribed fire was a success in terms of achieving the objectives of reducing fuels that could contribute to a crown fire and reducing dense tree regeneration in the understorey. The fire burned relatively consis-

TABLE 1 Characteristics and environmental conditions during a prescribed fire at the ponderosa pine site in the East Kootenay region of British Columbia

Parameter	Value
Date	April 22, 2004
Time of ignition	2:15 p.m.
Time of main fire out	6:00 p.m.
Initial air temperature (°C)	17
Maximum air temperature (°C)	22
Initial relative humidity (%)	35
Minimum relative humidity (%)	~24
Initial wind speed and direction	5–8 km/hr W/SW
Prevailing wind speed and direction	0–5 km/hr S/SW upper winds (main body to SE)
Canadian Forest Fire Danger Rating System Indices^a	
Fine Fuel Moisture Code (FFMC)	90.8
Duff Moisture Code (DMC)	44
Drought Code (DC)	399
Initial Spread Index (ISI)	7.8
Buildup Index (BUI)	69
Fire Weather Index (FWI)	22.0

a. Stocks et al. 1989.

tently across the study area, charring an average of 50% ($\pm 3.4\%$) of the ground surface. At least 25% of the ground surface was burned on every plot. Most trees were charred at the base to an average height of 2.2 m (0.6–4.5 m). The fire consumed 68% of the available coarse fuel on the site. Fuel loads of coarse woody debris (>7.1 cm in diameter) dropped from 9.4 to 6.4 m³/ha following the prescribed fire. Forest floor thickness was reduced by 33% as a result of the fire, decreasing from 1.8 to 1.2 cm.

At the Douglas-fir site, restoration treatments were conducted using partial cutting and slashing in a similar manner as that used at the ponderosa pine site, except that the treatments were conducted during June 1999. The partial-cutting harvest pass removed an average of 68 m³/ha of tree volume, leaving 59 m³/ha in the residual stand. Merchantable stem density decreased by 261 stems per hectare, leaving 243 stems per hectare on the site. Understorey light increased by an average of 27% following harvest. The Douglas-fir site was not subjected to a prescribed fire during the period of this study.

2.4 Data Analysis

The harvest and prescribed fire treatments resulted in increases of understorey light due to the removal of portions of the tree canopy. The amount of increased light was determined by using instrumentation to compare pre-harvest understorey light to post-harvest/post-burn understorey light at each macroplot. A post-hoc median split procedure was used to create a group of macroplots with low (or no) or high levels of increased light as a result of the harvest and burn treatments.

At the ponderosa pine site, the resulting low-light group consisted of macroplots with increased light levels between 0 and 33%, and averaging 17%, while the high-light group consisted of macroplots with increased light levels between 34 and 68%, and averaging 44%. These light categories corresponded

to basal area removal of 3 m²/ha for the low-light group and 16 m²/ha for the high-light group. The pre-treatment levels of understorey light in the two resulting light categories were exactly the same (34%), which suggested that post-treatment differences in other variates (such as herbaceous biomass) could be attributed with high confidence to increased light levels.

At the Douglas-fir site, the low-light group consisted of macroplots with increased light levels between 0 and 20%, and averaging 9%, while the high-light group consisted of macroplots with increased light levels between 21 and 41%, and averaging 32%. These light categories corresponded to basal area removal of 5.6 m²/ha for the low-light group and 17.1 m²/ha for the high-light group. The pre-treatment levels of understorey light in the two resulting light categories were very close (28% vs. 27%), which again suggested that post-treatment differences between the two light categories could be attributed with high confidence to increased light levels.

For both sites, the resulting spatial distribution of macroplots in the two light categories was reasonably well interspersed, and neither spatial distribution was correlated with local drainages or other topographic features (Figure 2). This suggested that topography and local drainages were likely not responsible for any observed differences between the two light categories.

The effect of partial-cut harvesting/slashing was tested by analyzing the response of herbaceous biomass and plant frequency over the 7-year period (Year) for the two understorey light groups (Light). Plant frequency was used instead of plant cover because it is less responsive to annual weather effects ("noise") but still tracks long-term trends. A repeated measures ANOVA was used to account for possible autocorrelation of the Year effect. The shape of the response variables over time was determined using single degree-of-freedom polynomial contrasts. The SAS procedure PROC MIXED was used for all analyses (SAS Institute 1988).

The response of total herbaceous biomass and total grass biomass was tested in addition to clipped herbaceous biomass categories (bunchgrasses, pinegrass, sedges, other grasses, and forbs). Plant frequency response variables were limited to eight plant species that occurred most frequently (> 8% plant frequency). The frequency response of exposed mineral soil was also examined.

Linear, non-linear, and multiple regression analyses were used to determine relationships among understorey light, growing-season precipitation, and herbaceous biomass. Non-linear curve fitting was conducted using linearized forms in SAS PROC REG (Sit and Poulin-Costello 1994).



FIGURE 2 Spatial distribution of macroplots in relation to local drainages and other topography for (A) ponderosa pine and (B) Douglas-fir sites in the East Kootenay region of British Columbia.

3 RESULTS

3.1 Ponderosa Pine Site

3.1.1 Herbaceous biomass

Comparison by light group The restoration treatments increased several herbaceous biomass categories at the ponderosa pine site. In 2006 total herbaceous biomass was more than double (Light $\times$ Year linear effect; $P < 0.05$) on more open (high-light) macroplots compared to less open (low-light) macroplots (Table 2, Figure 3). Herbaceous biomass also doubled on open macroplots compared to 1999, the pre-treatment year.

TABLE 2 Repeated measures ANOVA significance tests (Prob. $> F$) of herbaceous biomass response to light group (Light) and year at the ponderosa pine site from 1999 to 2006

Effect	Significance level (Prob. $> F$) of plant biomass								
	Num. DF ^a	Den. DF ^b	Bunchgrass	Pinegrass	Sedge	Other forbs	Combined grass	Grass	Total
Light	1	16	0.1865	0.0157	0.7044	0.0078	0.9388	0.0023	0.0502
Year	5	70	0.1246	0.0085	0.2594	0.0043	0.1808	< 0.0001	< 0.0001
Linear (L)	1	70	0.0272	0.0038	0.9238	0.2937	0.048	< 0.0001	< 0.0001
Quadratic (Q)	1	70	0.2053	0.6752	0.0691	0.2010	0.5527	0.1809	0.1882
Light $\times$ Year	5	70	0.5657	0.2048	0.7201	0.5796	0.9386	0.0627	0.1961
Light $\times$ Year (L)	1	70	0.2481	0.0387	0.3166	0.8329	0.799	0.0089	0.0183
Light $\times$ Year (Q)	1	70	0.4613	0.6182	0.9119	0.7118	0.5057	0.3015	0.4223

a Degrees of freedom used in the numerator

b Degrees of freedom used in the denominator

Bunchgrass—bluebunch wheatgrass (*Pseudoroegneria spicata*), rough fescue (*Festuca campestris*), Idaho fescue (*Festuca idahoensis*), spreading needlegrass (*Achnatherum richardsonii*), junegrass (*Koeleria macrantha*), needle-and-thread grass (*Hesperostipa comata*); **Pinegrass**—*Calamagrostis rubescens*; **Sedge**—*Carex* spp. (mostly *Carex concinnoides*); **Forbs**—a mix of 30–40 species, each usually with $< 2\%$ cover; **Other Grass**—all other non-bunchgrasses

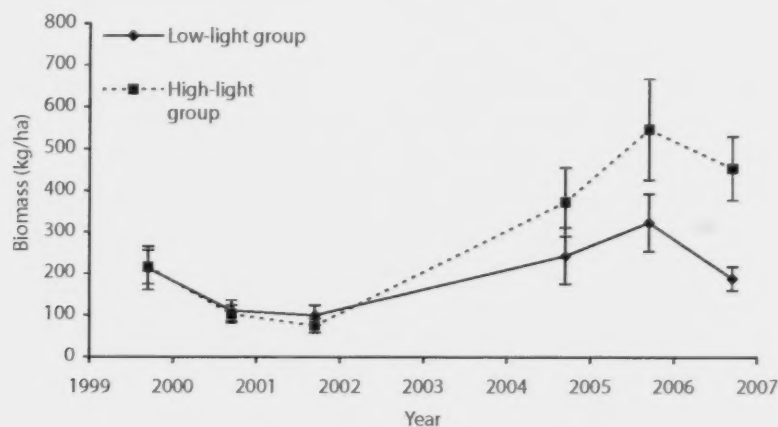


FIGURE 3 Total herbaceous biomass (mean $\pm$ SE) on low- and high-light macroplots at the ponderosa pine site in response to the June 2000 harvesting and April 2004 prescribed fire treatment.

A significant Light $\times$ Year linear effect suggests that the increasing trend in herbaceous biomass over time was steeper for the more open macroplots compared to the less open macroplots when examined using a straight-line model. The significant interaction also provides evidence that the relationship was independent of pre-existing (pre-harvest) difference between the herbaceous biomass of the light groups (Table 2, Figure 3).

Herbaceous biomass of combined grasses followed this same pattern but with even greater differences between the two light groups (Figure 4). This is probably because most of the herbaceous biomass increase in the high-light group was due to pinegrass, which had increased almost five-fold by 2006 (Figure 5). Pinegrass contributed 54% (152 kg/ha) of the grass biomass response, while bunchgrass contributed 43% (121 kg/ha).

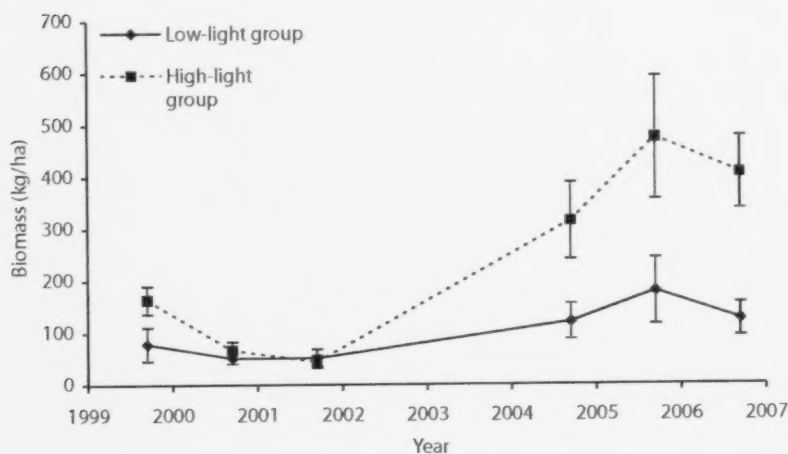


FIGURE 4 Herbaceous biomass of all grasses combined (mean $\pm$ SE) on low- and high-light macroplots at the ponderosa pine site in response to the June 2000 harvesting and April 2004 prescribed fire treatment.

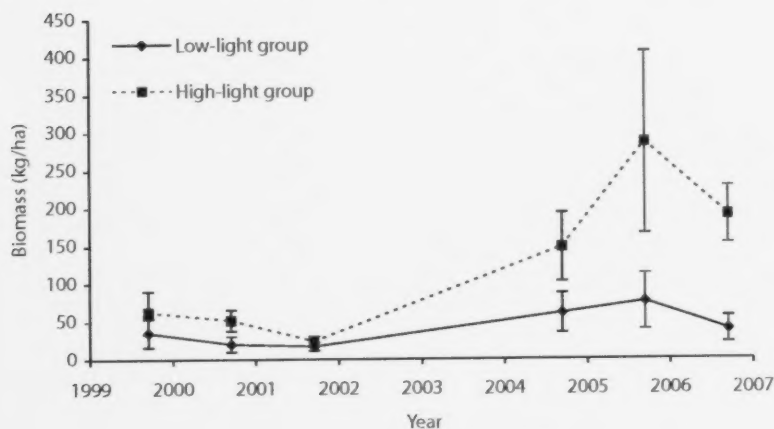


FIGURE 5 Herbaceous biomass of pinegrass (mean $\pm$ SE) on low- and high-light macroplots at the ponderosa pine site in response to the June 2000 harvesting and April 2004 prescribed fire treatment.

Bunchgrass biomass was too variable to yield statistically significant differences between the two light groups (Table 2), but it contributed positively to the combined grass category (Figures 4 and 6). Based on the plant frequency data, the bunchgrass category consisted mostly of spreading needlegrass (41%), junegrass (31%), and rough fescue (24%).

Sedge production was not at all responsive over time or to the light groups ($P > 0.05$; data not shown). Forb biomass was also not responsive to the light groups. There was a pre-harvest difference in forb biomass, which was perpetuated over the period of the study (significant Light main effect but no significant Light $\times$ Year effect) (Figure 7). The lack of response by forbs, combined with the strong increase by grasses, suggests that the plant community is moving towards greater grass dominance.

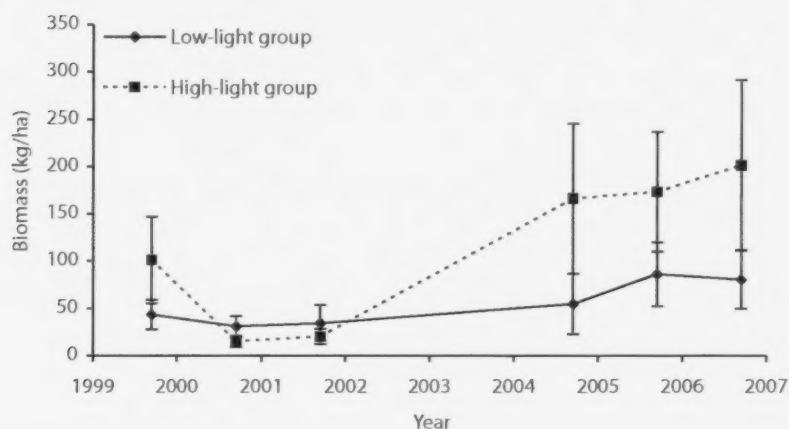


FIGURE 6 Herbaceous biomass of bunchgrasses (mean $\pm$ SE) on low- and high-light macroplots at the ponderosa pine site in response to the June 2000 harvesting and April 2004 prescribed fire treatment.

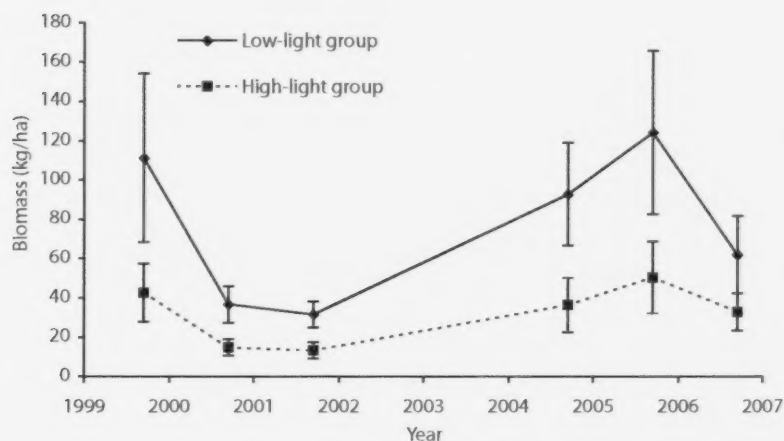


FIGURE 7 Herbaceous biomass of forbs (mean $\pm$ SE) on low- and high-light macroplots at the ponderosa pine site in response to the June 2000 harvesting and April 2004 prescribed fire treatment.

Comparison over years When examining trends over time, averaged over both light groups, all categories of herbaceous biomass except sedges had significant changes over the 6-year period. Grass categories (pinegrass, bunchgrass, and other grass) showed linear increases over time (Table 2). Forbs had a more complex response, decreasing initially, then recovering and decreasing again (Figure 7). This is supported by a significant cubic Year effect ($P=0.0005$; not shown). The general pattern of all herbaceous biomass categories showed an initial decrease or flat response for the first few years, followed by increases in 2004 and 2005. Linear increases over multiple years (2004–2005) suggest that plants were responding to increased light by growing in size or by colonizing new areas. The flat or decreasing response in the first few years is consistent with the possibility that mechanical damage due to harvesting equipment had occurred. There was also a deep drought during the 2000 and 2001 growing seasons, which likely contributed to poor forage development. Growing-season precipitation at the Johnson Lake fire weather station in 2000 and 2001 was only 49% and 43% of normal, respectively (Figure 1). The general decline in forage production in 2006 may have been weather related; however, weather recorded at the Johnson Lake fire weather station was very close to normal (total April–October precipitation: 111% of the 25-year normal; average April–October temperature: 103% of the 25-year normal).

Relationship of herbaceous biomass to understorey light The relationship of herbaceous biomass in 2006 to understorey light levels was examined using regression analysis. Grass biomass as a group (bunchgrass, pinegrass, and other grass) was positively related ($P=0.0001$; $R^2=0.64$) to understorey light and followed an exponential trend (Figure 8). Bunchgrass alone showed a similar but weaker relationship with understorey light ($P=0.019$; $R^2=0.30$; data not shown). Pinegrass biomass and other plant species groups did not have significant relationships with understorey light.

The regression relationship of grass biomass to understorey light was used to develop a table of predicted forage for various canopy closure levels (Table 3). This table can be used cautiously to determine expected grass forage levels 6 years following partial cutting and prescribed burning at similar sites. The predictions in this table are based on forage production values during 2006, when growing-season precipitation was close to normal (111% of the 25-year normal at the Johnson Lake fire weather station). Herbaceous biomass is known to vary with annual weather, and indeed, had a clear relationship with annual growing-season precipitation at the ponderosa pine site ($P<0.0001$; $R^2=0.21$). Therefore, values in Table 3 reflect only years of average growing-season precipitation.

The relationship of understorey herbaceous biomass to light was non-linear (exponential), and the greatest gains in forage developed (per tree removed) at > 50% canopy removal (Figure 8). In fact, 50% canopy removal produced only 20% of the grass forage potential for the site. It was necessary to remove 80% of the canopy to achieve 50% of the forage potential for the site (Table 3).

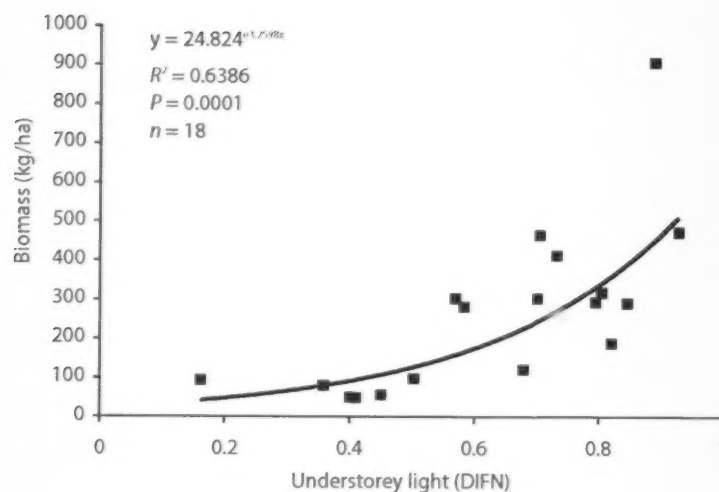


FIGURE 8 Herbaceous biomass of all grasses combined in 2006 at the ponderosa pine site in response to understorey light levels following the harvest and prescribed fire treatment. DIFN = diffuse non-interceptance.

TABLE 3 Predicted biomass of grasses at different canopy removal levels based on the modelled relationship of herbaceous biomass to understorey light in 2006 at the ponderosa pine site

Canopy removal (%)	Herbaceous biomass (kg/ha)	Proportion of total forage potential (%)
10	34	5
15	40	6
20	48	7
25	56	9
30	66	10
35	78	12
40	91	14
45	108	17
50	127	20
55	149	23
60	176	27
65	207	32
70	243	38
75	286	44
80	337	52
85	396	61
90	467	72

3.1.2 Plant frequency The plant community at the ponderosa pine site was somewhat different in 2006 compared to the pre-treatment condition (Appendix A1).

Comparison by light group The restoration treatments did not have any effect on plant species frequency at the ponderosa pine site. The analysis of macroplots grouped by light category did not detect any changes in important plant species frequencies, expressed as a percentage ($P > 0.05$), over the 6-year period (lack of Light $\times$ Year interaction) (Table 4). There was a pre-harvest difference in pinegrass frequency, which was perpetuated over the period of the study (Light main effect) (Figure 9).

TABLE 4 Repeated measures ANOVA significance tests of plant species frequency (%) and exposed mineral soil frequency (%) response to light group (Light) and year at the ponderosa pine site from 1999 to 2006

Effect	Significance level (Prob. > F) of plant species frequency										
	Num. DF ^a	Den. DF ^b	AMAL	ARUV	CACO	CARU	FECA	FRVI	PECO	Soil	STRI
Light	1	16	0.999	0.892	0.647	0.045	0.694	0.864	0.764	0.653	0.591
Year	5	80	0.002	<.0001	<.0001	<.0001	0.007	0.081	0.001	<.0001	0.364
Linear (L)	1	80	0.001	<.0001	0.002	<.0001	0.000	0.877	0.001	<.0001	0.544
Quadratic (Q)	1	80	0.701	0.247	0.948	0.796	0.416	0.010	0.173	0.426	0.169
Light × Year	5	80	0.812	0.750	0.987	0.193	0.571	0.683	0.668	0.447	0.829
Light × Year (L)	1	80	0.228	0.627	0.676	0.888	0.250	0.376	0.150	0.829	0.307
Light × Year(Q)	1	80	0.413	0.183	0.963	0.499	0.763	0.649	0.426	0.977	0.578

a Degrees of freedom used in the numerator

b Degrees of freedom used in the denominator

AMAL - saskatoon (*Amelanchier alnifolia*); ARUV - kinnikinnick (*Arctostaphylos uva-ursi*); CACO - northwestern sedge (*Carex concinnoides*); CARU - pinegrass (*Calamagrostis rubescens*); FECA - rough fescue (*Festuca campestris*); FRVI - wild strawberry (*Fragaria virginiana*); PECO - yellow penstemon (*Penstemon confertus*); Soil - exposed mineral soil; STRI - spreading needlegrass (*Achnatherum richardsonii*)

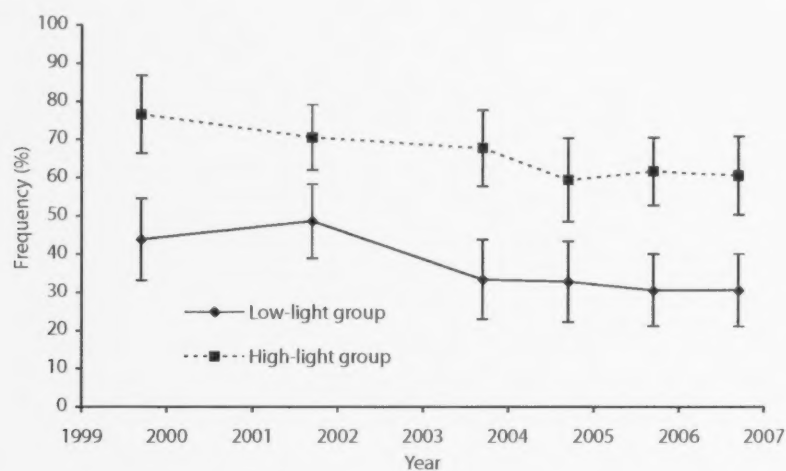


FIGURE 9 Frequency of pinegrass (mean $\pm$ SE) on low- and high-light macroplots at the ponderosa pine site in response to the June 2000 harvesting and April 2004 prescribed fire treatment.

Comparison over years When examining trends over time, averaged over both light groups, every plant species except spreading needlegrass decreased in frequency over the period of the study (Year effect; Table 4). Most commonly, the largest decreases occurred following the prescribed fire in April 2004. Saskatoon (Figure 10), kinnikinnick (Figure 11), and northwestern sedge (Figure 12) showed this type of response. This suggests that these species were sensitive to the low-intensity prescribed fire used at the ponderosa pine site. Antelope-brush was particularly sensitive to the effects of the restoration treatments, decreasing ($P < 0.0001$) from 6% to <1% over the period of the study, with both the combined harvest treatment and prescribed fire contributing to its decline (data not shown).

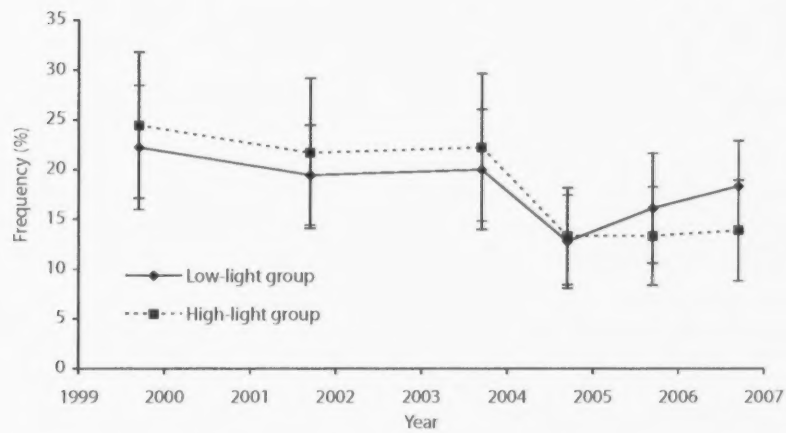


FIGURE 10 Frequency of saskatoon (mean $\pm$ SE) on low- and high-light macroplots at the ponderosa pine site in response to the June 2000 harvesting and April 2004 prescribed fire treatment.

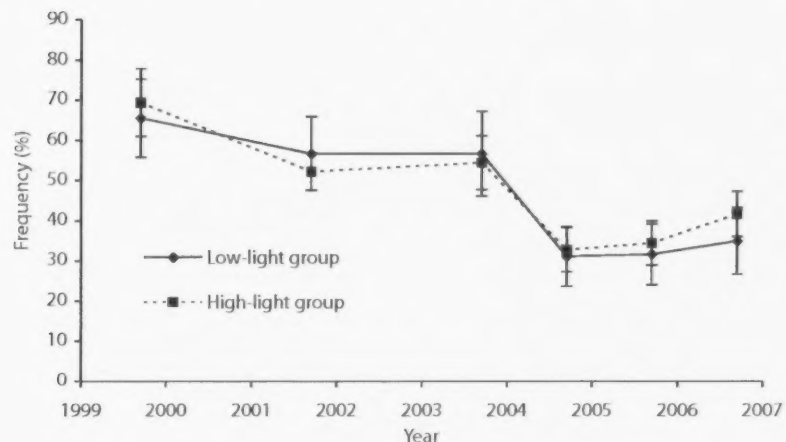


FIGURE 11 Frequency of kinnikinnick (mean $\pm$ SE) on low- and high-light macroplots at the ponderosa pine site in response to the June 2000 harvesting and April 2004 prescribed fire treatment.

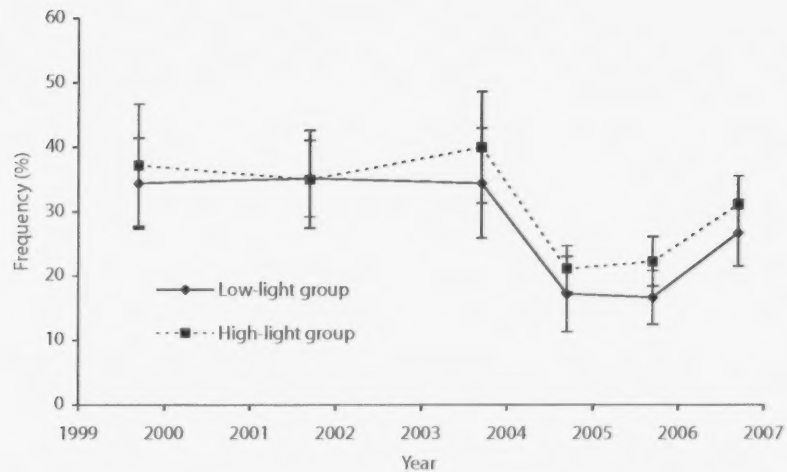


FIGURE 12 Frequency of northwestern sedge (mean $\pm$ SE) on low- and high-light macroplots at the ponderosa pine site in response to the June 2000 harvesting and April 2004 prescribed fire treatment.

Rough fescue and yellow penstemon (*Penstemon confertus*) decreased linearly over time (Figures 13 and 14). Decreasing plant frequency during 2000 and 2001 may have been due to a drought period that occurred in 2000 and 2001 (Figure 1). Growing-season precipitation at the Johnson Lake fire weather station in 2000 and 2001 was only 49% and 43% of normal, respectively. Wild strawberry (*Fragaria virginiana*) initially decreased then recovered to pre-harvest levels following the prescribed fire (Figure 15). This suggests that wild strawberry frequency can be increased by the use of low-intensity prescribed fire.

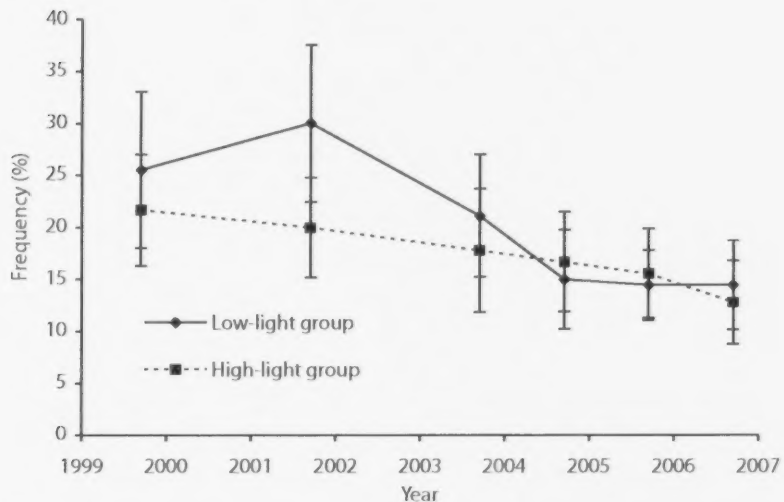


FIGURE 13 Frequency of rough fescue (mean $\pm$ SE) on low- and high-light macroplots at the ponderosa pine site in response to the June 2000 harvesting and April 2004 prescribed fire treatment.

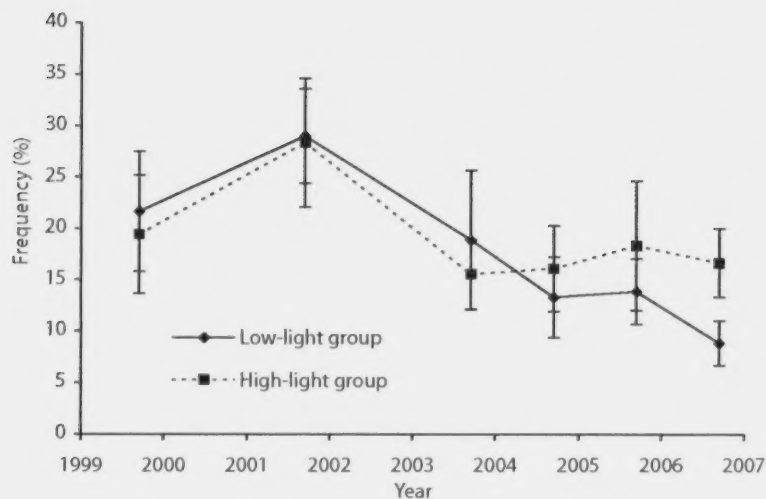


FIGURE 14 Frequency of yellow penstemon (mean $\pm$ SE) on low- and high-light macroplots at the ponderosa pine site in response to the June 2000 harvesting and April 2004 prescribed fire treatment.

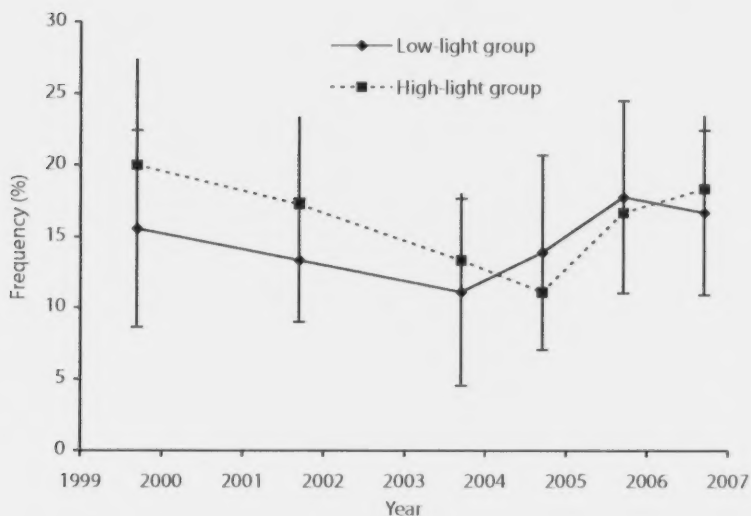


FIGURE 15 Frequency of wild strawberry (mean $\pm$ SE) on low- and high-light macroplots at the ponderosa pine site in response to the June 2000 harvesting and April 2004 prescribed fire treatment.

Grazing use by cattle and/or elk likely affected plant frequency at the ponderosa pine site. However, grazing during the May–September period of 2004–2006 was relatively light, averaging 18% forage use. No measurement of overwinter/early spring grazing by wild ungulates was made. Elk were observed in the vicinity of the study site in every sampling year. It is notable, however, that plant species not usually included in the diet of wild ungulates, such as kinnikinnick (Ross 1997), were reduced to the same extent as rough

fescue and saskatoon. This suggests that a factor other than grazing was the main driver for decreasing plant frequency.

The frequency of Douglas-fir seedlings and saplings decreased ($P < 0.01$) following harvesting but recovered by 2003. There were sharp losses of Douglas-fir in 2004, which can be attributed directly to the effects of the prescribed fire. The prescribed fire eliminated Douglas-fir on most macroplots, resulting in 88% loss of Douglas-fir seedlings and saplings.

Exposed mineral soil The amount of exposed mineral soil increased ($P < 0.05$) over time during at least two separate periods (Figure 16). This is supported by a significant quartic Year effect ($P < 0.0001$; not shown). An initial increase in exposed mineral soil from the pre-treatment year (1999) to 2001 may have been due to mechanical damage from harvesting equipment and/or to a drought period in 2000 and 2001 (Figure 1). A steep increase in exposed mineral soil frequency from 2003 to 2004 was no doubt due to the prescribed fire in April 2004 (Figure 16). The fire resulted in a 40% increase in exposed mineral soil.

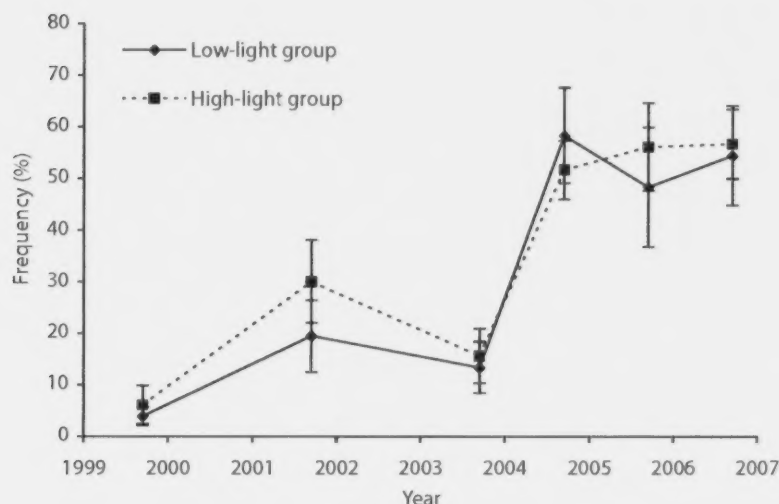


FIGURE 16 Frequency of exposed mineral soil (mean $\pm$ SE) on low- and high-light macroplots at the ponderosa pine site in response to the June 2000 harvesting and April 2004 prescribed fire treatment.

A regression analysis of exposed mineral soil versus bark charring provided further evidence of the effect of fire on mineral soil exposure. It is known that fire will char the bole of standing trees to greater heights with increasing fire intensity (Alexander 1982; Beverly and Martell 2003). Greater bark char height as a result of the prescribed fire was positively related to more mineral soil exposure ($P = 0.015$; $R^2 = 0.32$) (Figure 17), indicating that there was a relationship between fire intensity and exposed soil.

Pinegrass versus rough fescue One of the key objectives of dry forest restoration is to increase the abundance of important forage species such as rough fescue, while reducing the abundance of pinegrass, the co-dominant competi-

itor at the ponderosa pine site. The frequency of these two species decreased over the 6-year period, perhaps in response to the April 2004 prescribed fire, among other factors (Figure 18). In order to compare the performance of the two grass species, the ratio of pinegrass frequency to rough fescue frequency was calculated, and a regression was conducted on those values across years. The ratio increased from about 3.5:1 to 4.7:1, indicating that rough fescue declined relative to pinegrass at the ponderosa pine site ($P = 0.09$; $R^2 = 0.54$; $n = 6$).

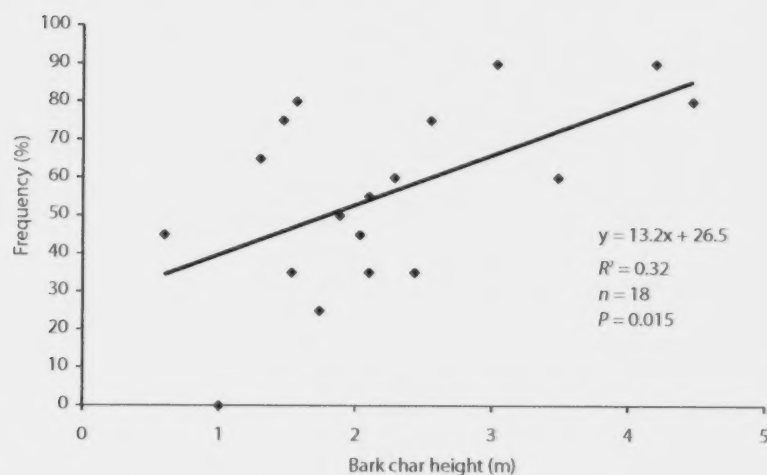


FIGURE 17 Frequency of mineral soil exposure in relation to bark char height following a prescribed fire at the ponderosa pine site on April 22, 2006.

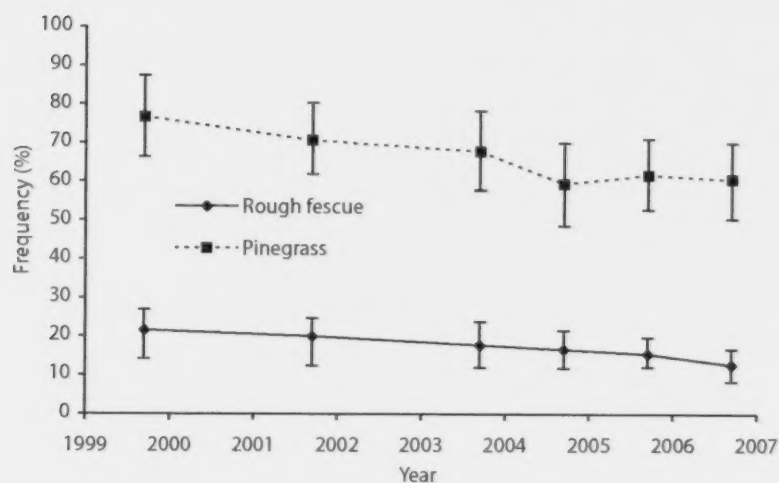


FIGURE 18 Frequency of rough fescue and pinegrass (mean $\pm$ SE) on high-light macroplots at the ponderosa pine site from 1999 to 2006.

3.2 Douglas-fir Site

3.2.1 Herbaceous biomass

Comparison by light group Total herbaceous biomass was 70% greater on more open (high-light) macroplots ($P=0.042$) than on less open (low-light) macroplots at the Douglas-fir site (Figure 19, Table 5). Similar to the ponderosa pine site, the difference in response was due primarily to a steeper linear increase over time for high-light macroplots and not to a difference in any one year (significant Light $\times$ Year linear polynomial contrast) (Table 5). Most of the biomass increase in 2006 was from forbs (58% of total biomass increase; 88 kg/ha). Pinegrass (21%; 31 kg/ha) and bunchgrass (21%; 32 kg/ha) contributed equal amounts to total herbaceous biomass.

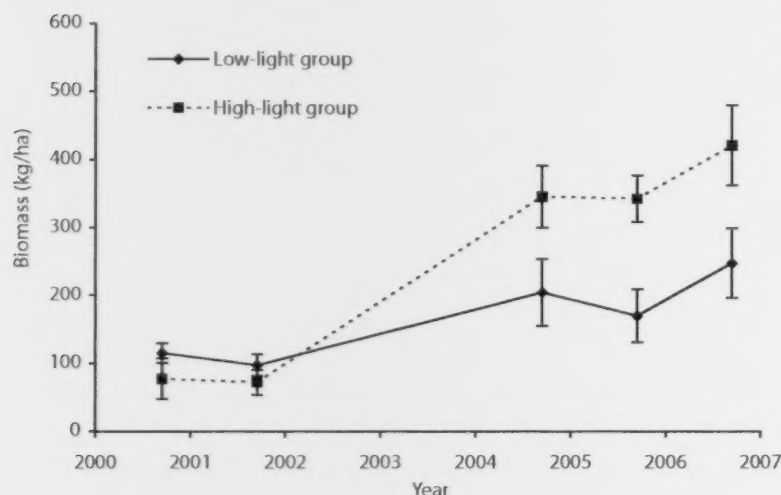


FIGURE 19 Total herbaceous biomass (mean $\pm$ SE) on low- and high-light macroplots at the Douglas-fir site in response to the June 1999 harvesting treatment.

TABLE 5 Repeated measures ANOVA significance tests of herbaceous biomass response to light group (Light) and Year at the Douglas-fir site from 2000 to 2006

Effect	Num. DF ^a	Den. DF ^b	Significance level (Prob. > F) of plant biomass					
			Bunchgrass	Pinegrass	Sedge	Combined forbs	Grass	Total
Light	1	16	0.8683	0.6903	0.8220	0.1604	0.7401	0.2284
Year	4	70	0.3954	0.0002	0.1510	0.2401	<.0001	0.0020
Linear (L)	1	70	0.3999	<.0001	0.0270	0.0339	<.0001	0.0002
Quadratic (Q)	1	70	0.3087	0.6847	0.3413	0.6092	0.9693	0.9921
Light $\times$ Year	4	70	0.2101	0.6086	0.5115	0.1808	0.3129	0.3546
Light $\times$ Year (L)	1	70	0.0541	0.3482	0.7284	0.0152	0.0674	0.0418
Light $\times$ Year (Q)	1	70	0.2377	0.5339	0.1590	0.8983	0.8363	0.6727

a Degrees of freedom used in the numerator

b Degrees of freedom used in the denominator

Bunchgrass bluebunch wheatgrass (*Pseudoroegneria spicata*), rough fescue (*Festuca campestris*), Idaho fescue (*Festuca idahoensis*), spreading needlegrass (*Achnatherum richardsonii*), junegrass (*Koeleria macrantha*), needle-and-thread grass (*Hesperostipa comata*); **Pinegrass** *Calamagrostis rubescens*; **Sedge** *Carex* spp. (mostly *Carex concinnoides*); **Forbs** a mix of 30–40 species, each usually with <2% cover

Herbaceous biomass of bunchgrass was initially greater on low-light macroplots compared to high-light macroplots due to differences that existed pre-treatment (Figure 20). After the harvest treatment, bunchgrass biomass gradually increased on high-light macroplots while remaining relatively unchanged on low-light macroplots ($P < 0.05$; Table 5). By 2006, bunchgrass biomass was almost 2.5 times greater (44 kg/ha vs. 13 kg/ha) on high-light than on low-light macroplots. In 2006, the bunchgrass category consisted mostly of rough fescue (37% of total bunchgrass) and spreading needlegrass (30%), with lesser amounts of bluebunch wheatgrass (15%).

The biomass of forbs increased steadily on high-light macroplots following the harvest treatment but did not respond at all on low-light macroplots ($P < 0.05$; Table 5). By 2006 forb biomass was three times greater (125 kg/ha vs. 37 kg/ha) on high-light than on low-light macroplots (Figure 21). The forb group consisted of 20 species and was dominated by smooth aster (*Aster laevis*) (15% of total forbs), wild strawberry (10%), and narrow-leaved hawkweed (*Hieracium umbellatum*) (10%). Exotic species were removed from the data set for the analysis of this group.

Herbaceous biomass of all grasses combined was not responsive to increased light ($P > 0.05$) (Figure 22). Similarly, sedges and pinegrass were not responsive to increased light ($P > 0.05$) (Figures 23 and 24, Table 5). Absence of a response to the light groupings indicates that the difference in light was not great enough to result in differences in herbaceous biomass, or that the variability of the data was too high for differences to be detected.

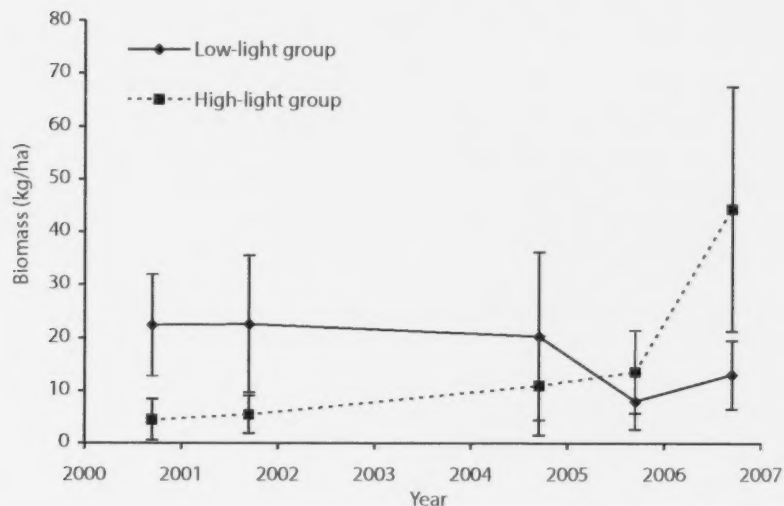


FIGURE 20 Herbaceous biomass of bunchgrass (mean $\pm$ SE) on low- and high-light macroplots at the Douglas-fir site in response to the June 1999 harvesting treatment.

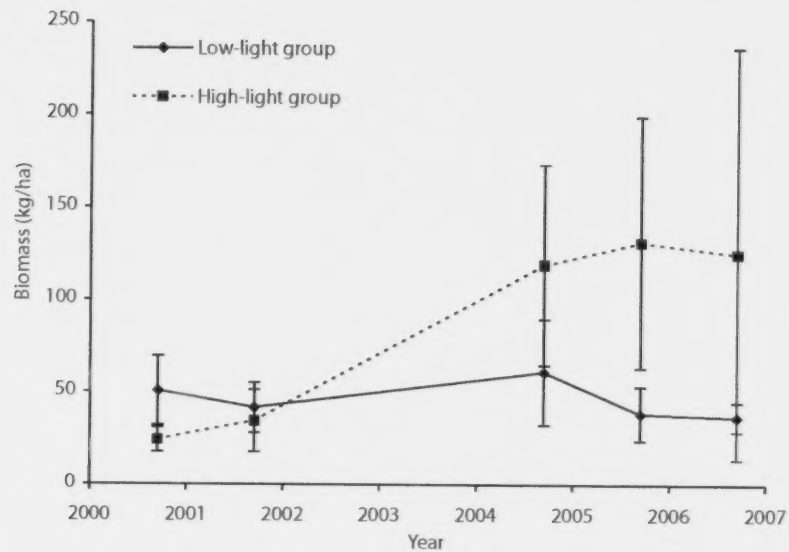


FIGURE 21 Herbaceous biomass of forbs (mean $\pm$ SE) on low- and high-light macroplots at the Douglas-fir site in response to the June 1999 harvesting treatment.

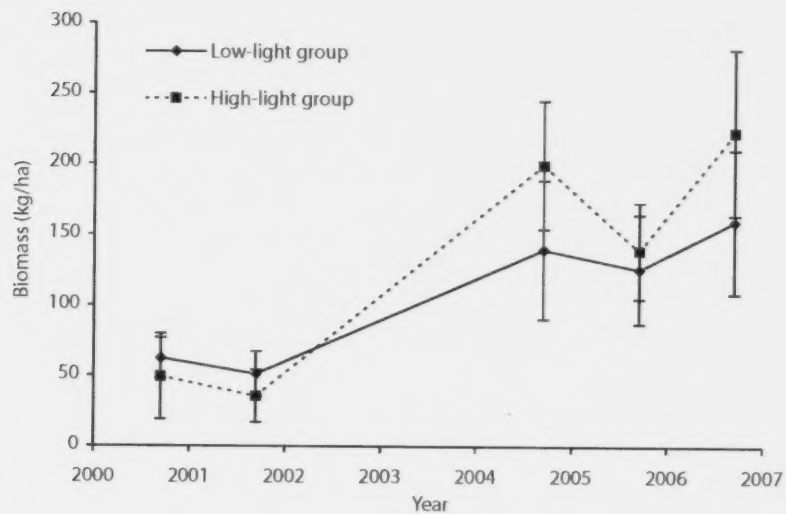


FIGURE 22 Herbaceous biomass of all grasses combined (mean $\pm$ SE) on low- and high-light macroplots at the Douglas-fir site in response to the June 1999 harvesting treatment.

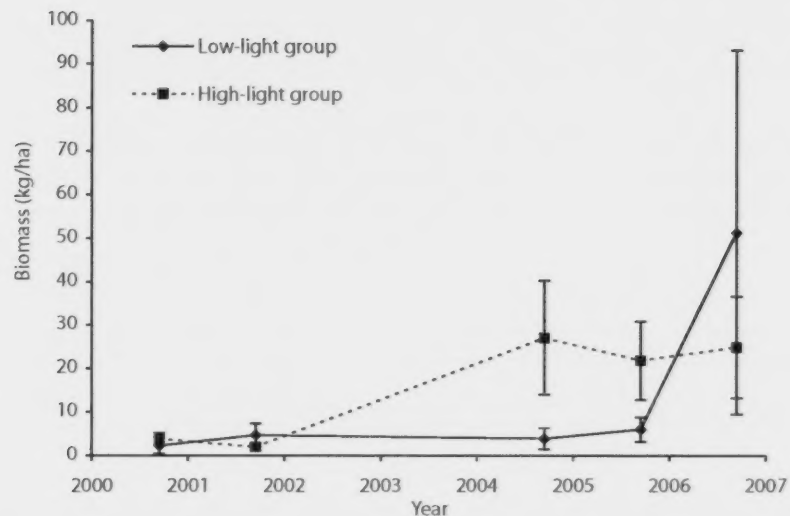


FIGURE 23 Herbaceous biomass of sedges (mean $\pm$ SE) on low- and high-light macroplots at the Douglas-fir site in response to the June 1999 harvesting treatment.

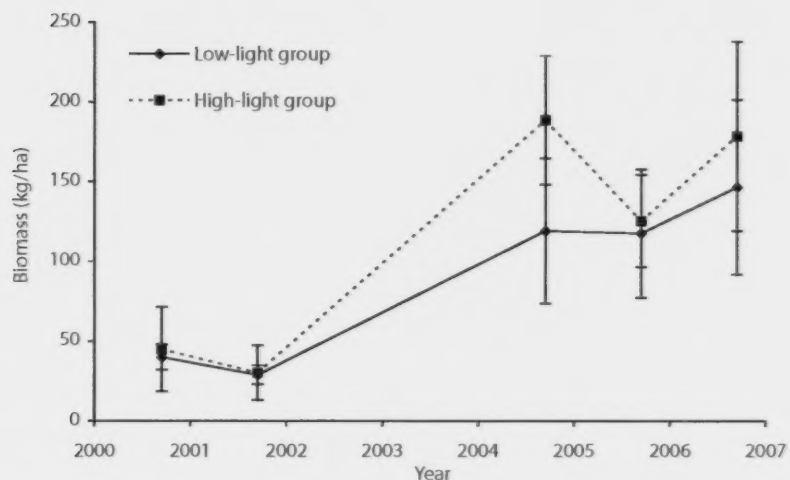


FIGURE 24 Herbaceous biomass of pinegrass (mean $\pm$ SE) on low- and high-light macroplots at the Douglas-fir site in response to the June 1999 harvesting treatment.

Comparison over years When examining trends over time, averaged over both light groups, all categories of herbaceous biomass except for bunchgrass increased linearly ($P < 0.05$) over the 6-year period (Table 5 Year linear effects). The combined grass category and pinegrass showed more complex increases over time—increasing after an initial lag, then decreasing in 2005, then increasing again ($P < 0.05$ Year quartic effects; not shown) (Figures 22 and 24). As at the ponderosa pine site, the lag in response in the first few years was consistent with the possibility that mechanical damage due to harvesting equipment had occurred. There was also a deep drought during the

2000 and 2001 growing seasons, which likely contributed to poor forage development early on. An increase in herbaceous biomass in 2004 may have been due to a particularly wet August in which there were 6 days of rainfall >10 mm and a total of 103 mm (Figure 1). Forage plots were clipped in September. Total biomass and sedges responded linearly over time in response to increased canopy opening, indicating progressive plant development following release from shading (Table 5, Figures 19 and 23).

Relationship of herbaceous biomass to understorey light and precipitation

The relationship of 2006 herbaceous biomass to understorey light levels was examined using regression analysis. Herbaceous biomass in 2006 was not significantly related to understorey light levels ($P > 0.05$) for any of the plant species or groups at the Douglas-fir site. Similar to herbaceous biomass at the ponderosa pine site, annual herbaceous biomass had a clear relationship with annual growing-season precipitation ($P = 0.0002$; $R^2 = 0.24$).

3.2.2 Plant frequency The plant community at the Douglas-fir site was somewhat different in 2006 compared to the pre-treatment condition (Appendix A2).

Comparison by light group The restoration treatments had an effect on the frequency of only one plant species at the Douglas-fir site. Kinnikinnick decreased sharply following harvesting, but only on macroplots in the high-light group (Figure 25) (Light $\times$ Year interaction; Table 6). It is possible that disturbance from the equipment used for spacing/slashing created more disturbance on the high-light areas than on the low-light areas, which may have injured or killed kinnikinnick on the high-light macroplots. Kinnikinnick decreased sharply again in 2004, but only on macroplots in the low-light group.

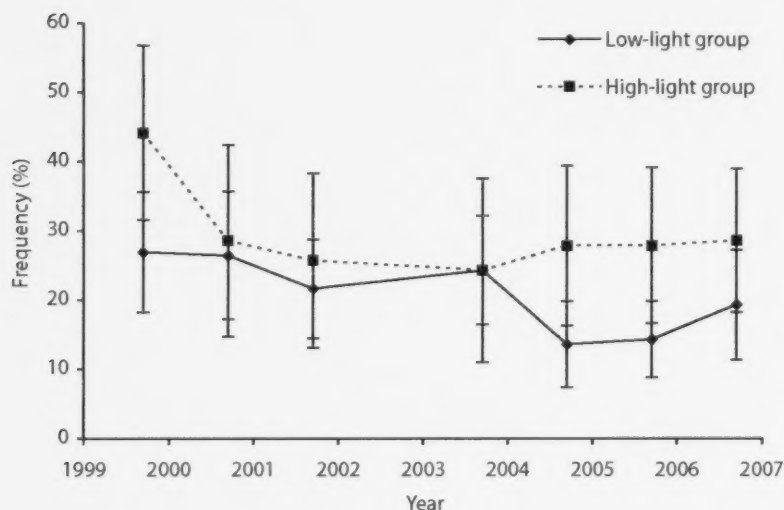


FIGURE 25 Frequency of kinnikinnick (mean $\pm$ SE) on low- and high-light macroplots at the Douglas-fir site in response to the June 1999 harvesting treatment.

TABLE 6 Repeated measures ANOVA significance tests of plant species frequency and exposed mineral soil frequency in response to light group (Light) and year at the Douglas-fir site from 1999 to 2006

Effect	Significance level (Prob. > F) of plant species frequency										
	Num. DF ^a	Den. DF ^b	AMAL	ARUV	CACO	CARU	FECA	FRVI	PSME	Soil	SPBE
Light	1	12	0.9408	0.5398	0.2060	0.6735	0.2743	0.4808	0.0792	0.7775	0.3818
Year	6	72	0.6454	0.0034	0.1756	0.0698	0.0041	0.0469	0.2954	<.0001	0.4593
Linear (L)	1	72	0.3076	0.0026	0.2269	0.1075	0.0002	0.1297	0.3458	0.6868	0.1838
Quadratic (Q)	1	72	0.3676	0.0113	0.2601	0.5522	0.7174	0.1055	0.4324	0.0074	0.9705
Light × Year	6	72	0.7163	0.0586	0.7317	0.9914	0.3998	0.6405	0.6816	0.4810	0.3549
Light × Year (L)	1	72	0.1400	0.7695	0.6538	0.6631	0.2803	0.0856	0.5230	0.9898	0.2695
Light × Year (Q)	1	72	0.2623	0.0955	0.9423	0.8153	0.4013	0.7591	0.8486	0.4365	0.8852

a Degrees of freedom used in the numerator

b Degrees of freedom used in the denominator

AMAL – saskatoon (*Amelanchier alnifolia*); ARUV – kinnikinnick (*Arctostaphylos uva-ursi*); CACO – northwestern sedge (*Carex concinnoides*); CARU – pinegrass (*Calamagrostis rubescens*); FECA – rough fescue (*Festuca campestris*); FRVI – wild strawberry (*Fragaria virginiana*); PSME – Douglas-fir (<1.5 m height) (*Pseudotsuga menziesii*); Soil – exposed mineral soil; SPBE – birch-leaved spirea (*Spiraea betulifolia*)

The frequency of exposed mineral soil was greater on the high-light than on the low-light macroplots, particularly in the first 4 years after harvesting (Table 6, Figure 26). This supports an explanation that ground-based harvesting equipment resulted in high disturbance at the site. An unknown event in late summer 2003–spring 2004 resulted in an increase in exposed mineral soil but only on macroplots in the low-light group.

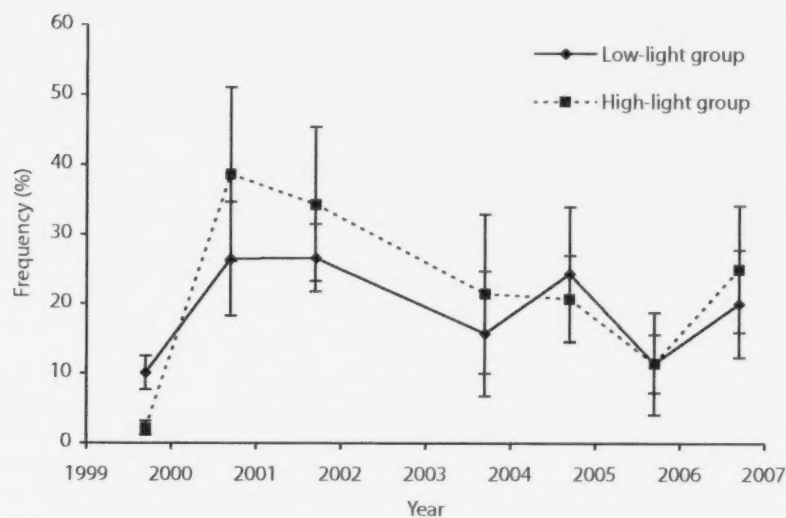


FIGURE 26 Frequency of exposed mineral soil (mean $\pm$ SE) on low- and high-light macroplots at the Douglas-fir site in response to the June 1999 harvesting treatment.

Comparison over years When examining trends over time, averaged over both light groups, rough fescue decreased in frequency over time (Table 6). Rough fescue decreased steadily after 2001, followed by a slight recovery after 2004 (Figure 27). Overall, rough fescue frequency dropped by 30% from pre-harvest levels. The decrease may have been due to a combination of drought and overgrazing by livestock and elk.

Wild strawberry increased by 79% over the 1999–2006 period (Table 6, Figure 28). Saskatoon, northwestern sedge, pinegrass, Douglas-fir saplings, and birch-leaved spirea had no overall changes in frequency ($P > 0.05$) over the study period (Table 6).

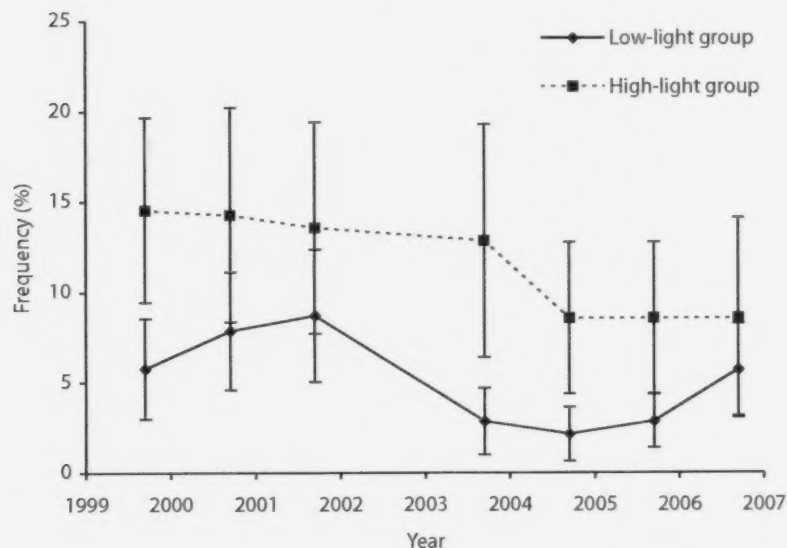


FIGURE 27 Frequency of rough fescue (mean $\pm$ SE) on low- and high-light macroplots at the Douglas-fir site in response to the June 1999 harvesting treatment.

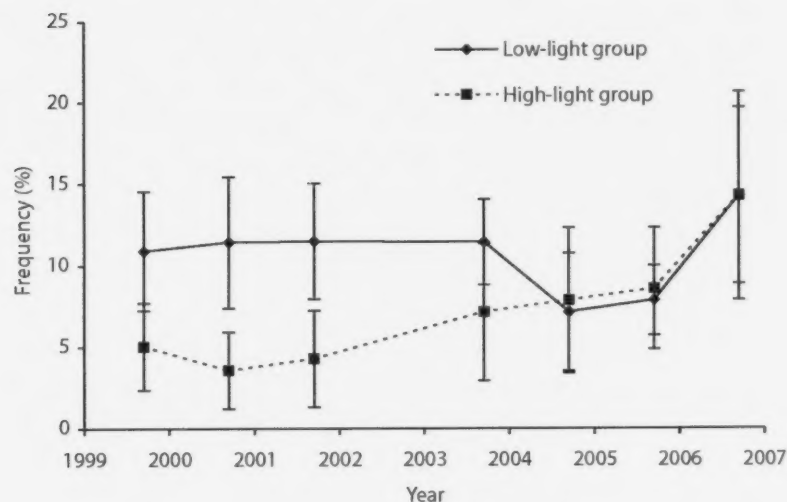


FIGURE 28 Frequency of wild strawberry (mean $\pm$ SE) on low- and high-light macroplots at the Douglas-fir site in response to the June 1999 harvesting treatment.

The frequency of rough fescue and pinegrass both decreased slightly over the 1999–2006 period on high-light macroplots (Figure 29), indicating that these plants were not colonizing vacant areas at all. The relative frequency of bunchgrass versus pinegrass changed over the 1999–2006 period. The ratio of pinegrass to rough fescue increased from 6.4:1 to 8.3:1 ($P = 0.042$; $R^2 = 0.60$; $n = 7$). This indicates that rough fescue declined relative to pinegrass at the Douglas-fir site.

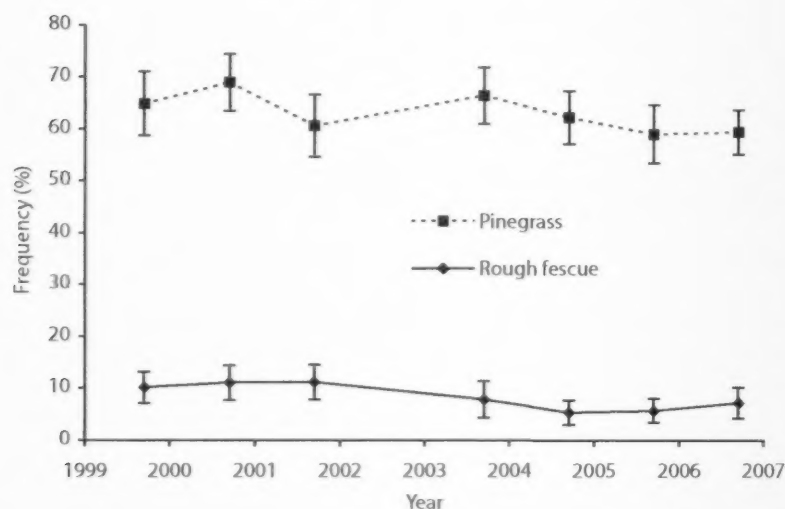


FIGURE 29 Frequency of rough fescue (mean $\pm$ SE) and pinegrass at the Douglas-fir site from 1999 to 2006.

4 DISCUSSION

4.1 Ponderosa Pine Site

4.1.1 Herbaceous biomass Restoration treatments that created greater light in the understory (44% vs. 17%) resulted in a doubling of total herbaceous biomass at the ponderosa pine site. Most of the forage increase was due to grass biomass, including pinegrass and bunchgrasses. The forage response developed over time after an initial lag of 2–4 years and was most evident by years 5 and 6 following treatment. The lag in response may have been due to mechanical damage to the vegetation due to harvesting equipment, since the site was harvested during June–July 2000 when most vegetation was actively growing (Page et al. 2005). It is also likely that drought during the 2000 and 2001 growing seasons exacerbated the negative effect of the site disturbance. Similar restoration treatments that are followed by years of normal growing-season precipitation can be expected to produce increases in herbaceous biomass in less time. Restoration treatments that result in less plant damage, such as dormant-season harvesting, are also likely to speed up herbaceous biomass response.

The restoration treatments resulted in a shift in the plant community toward more grasses and fewer forbs and shrubs. This trend was also reported for an eastern Washington ponderosa pine stand following thinning (McConnell and Smith 1970).

A regression model derived from 2006 herbaceous biomass/light relationships at the ponderosa pine site predicted that 80% canopy removal is required to achieve 50% of the forage potential for the site. This is somewhat comparable to an Arizona study that showed that 90% removal of ponderosa pine canopy was required to achieve 50% of the understorey forage potential (Jameson 1967). Canopy/understorey biomass relationships from wetter forests such as those in the Interior Douglas-fir zone are quite different. Only 20–40% canopy removal was required to achieve 50% of the forage potential at three British Columbia sites dominated by Douglas-fir (Dodd et al. 1972). In addition to shading, it is possible that moisture competition from ponderosa pine trees is a contributing factor to the suppression of understorey forage under dense canopies. As moisture becomes less limiting in higher-elevation forests, moisture competition plays a reduced role in the understorey. The lack of a significant regression relationship between herbaceous biomass and understorey light at the Douglas-fir site provides some evidence to support this.

4.1.2 Plant frequency Despite an increase in herbaceous biomass, the frequency of most plant species was not different on more open canopy areas compared to those with a relatively more closed canopy. This indicates that little colonization of unvegetated areas occurred during the study period. In fact, increases in the frequency of exposed mineral soil, especially following the prescribed fire, indicate that more unvegetated areas were created. Plant biomass increases were likely due to the release of existing plants that were previously shaded by trees or were kept at low vigour by competition with tree roots for moisture and nutrients. General decreases in the frequency of late seral plant species over time, as observed at the ponderosa pine site, indicate a retrogression of the plant community, especially when exposed mineral soil increases over the same period (Delesalle et al. 2009). Most of the reduction in plant frequency occurred following the prescribed fire in spring 2004. In 2006, the frequency of exposed mineral soil at the site was 57%, while the percent cover of exposed mineral soil was 16%. This level of mineral soil exposure is a concern because of the possibility of soil erosion and/or weed invasion. One of the stated objectives of ecosystem restoration in the East Kootenay region, namely “no mineral soil exposure” (Bond 2006), was clearly not met. Exposed mineral soil is expected to be < 5% cover on rough fescue–antelope-brush grasslands in the East Kootenay region at reference condition (Delesalle et al. 2009). Despite the apparent risk, there were very few weeds at the ponderosa pine site in 2006 and none that are defined as noxious weeds for the area (BCMFLNRO 2012b).

The prescribed fire resulted in an 88% reduction in Douglas-fir seedlings and saplings at the site. This represents success in achieving the objective of reducing regenerating conifers (Harris 2011). The prescribed fire also consumed 68% of the available coarse fuel (> 7.1 cm diameter) on the site, thus reducing the risk of catastrophic future fire and increasing ease of access by livestock and wild ungulates. Nonetheless, these benefits should be carefully considered against the negative effects of increased mineral soil exposure and plant mortality.

Increasing the proportion of bunchgrass in the understorey is one of the objectives of ecosystem restoration in the East Kootenay region (Bond 2006). The dominant bunchgrass at the ponderosa pine site, rough fescue, declined

relative to pinegrass. Although pinegrass is a suitable forage species during the growing season, it has little value in the dormant season, especially when covered by snow. The absolute amount of forage contributed by bunchgrass biomass increased by 100 kg/ha after 6 years in response to the treatments.

4.2 Douglas-fir Site

4.2.1 Herbaceous biomass Restoration treatments that created an average of 32% more understorey light at the Douglas-fir site resulted in a 70% increase in herbaceous biomass after 7 years. Most of the forage increase was due to forb biomass (88 kg/ha), as there was only about 10 kg/ha of additional rough fescue. The total forage response developed steadily over time after an initial lag of 2–4 years. The same lag in response was noted at the ponderosa pine site and was likely due to the same reasons (i.e., mechanical damage due to harvesting, and drought).

The restoration treatment did not result in a shift in the plant community towards grasses as it did at the ponderosa pine site. It is possible that the prescribed fire at the ponderosa pine site was responsible for the plant community shift. Most grasses are more fire resistant than forbs due to the protected location of the meristem (Wikeem and Strang 1983).

4.2.2 Plant frequency The restoration treatment affected the frequency of kinnikinnick but not of any other plant species. As at the ponderosa pine site, a general lack of increased plant frequency in the understorey in areas where the canopy was removed indicates that colonization of gaps was not occurring.

Early increases in the frequency of exposed mineral soil were likely a result of the harvesting activity. The lack of increased mineral soil exposure in 2005 supports the suggestion that prescribed fire caused the increase in mineral soil exposure at the ponderosa pine site, since a fire treatment was not conducted at the Douglas-fir site.

The decrease in rough fescue and the increase in wild strawberry indicates that the plant community retrogressed because rough fescue is a desirable, late seral species (Delesalle et al. 2009), while wild strawberry is known to increase with disturbance. Unlike at the ponderosa pine site, however, exposed mineral soil decreased toward the end of the study period. Nonetheless, the percent cover of exposed mineral soil, at 16%, fails to meet the reference condition of < 5% for rough fescue–antelope-brush grasslands of the East Kootenay region (Delesalle et al. 2009). As at the ponderosa pine site, rough fescue declined relative to pinegrass.

5 CONCLUSIONS

It is evident that desirable plant species such as rough fescue have not yet been able to reproduce substantially with the treatments employed and under the environmental conditions experienced over the study period. Possible limiting factors include drought and grazing by cattle, elk, and deer. Nonetheless, these factors are not unexpected along the east slopes of the Rocky Mountains in the East Kootenay region. Multi-species grazing is a common occurrence and drought is relatively common in this environment.

Rough fescue may eventually dominate at the ponderosa pine site and the Douglas-fir site provided that conditions conducive to its reproduction are maintained for sufficient time. Rough fescue is a long-lived species that reproduces primarily by seed. Seed production is very erratic, and several years may pass without appreciable seed set (Anderson 2006). Heavy grazing can substantially reduce seed production (Johnston et al. 1969). Rough fescue establishment from seed is episodic and dependent on proper environmental conditions in consecutive years for both seeds and seedlings. It is likely that intermediate plant communities formed by species with greater reproductive potential than rough fescue will occur first. Ross and Wikeem (2010) reported that 10 years were required to achieve full recovery of bluebunch wheatgrass and 22 years were required to achieve full recovery of rough fescue following severe grazing disturbance in the East Kootenay region.

Not all sites will necessarily benefit from prescribed fire. Although further sampling is required to properly assess changes in the plant community at the ponderosa pine site, early results suggest that prescribed fire may have caused more damage than good. The net effect of prescribed fire should be carefully considered before being implemented. The presence of invasive alien plant species at or near the site is an indicator that prescribed fire should be used with caution.

As documented by this study, increases in herbaceous biomass can be achieved in a relatively short time following restoration; however, beneficial changes in plant community composition are much less certain. In fact, 6 years after restoration treatments, the opposite was found to occur. Pinegrass increased relative to rough fescue at both sites. It is recommended that the planning horizon for the objective of achieving beneficial plant species composition changes be set at 20–50 years to reflect the slow nature of this process. In addition, it is recommended that for the objective of achieving short-term gains in bunchgrass biomass, sites that have a high density of pre-existing bunchgrass plants in a suppressed state due to light constraints should be selected. This was also a major conclusion of the Miller Road study that was conducted in similar plant communities in the East Kootenay region (Ross 2001). Restoration of “bunchgrass-suppressed” stands is likely to result in immediate increases in bunchgrass herbaceous biomass and should be considered as the highest priority for achieving an objective of increased forage.

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APPENDIX A1 Plant species frequency in 1999 (pre-treatment) and 2006 at the ponderosa pine site.

Common name	Scientific name	1999	2006
Grass and grasslike			
bluebunch wheatgrass	<i>Pseudoroegneria spicata</i>	6	2
Canada bluegrass	<i>Poa compressa</i>	<1	4
junegrass	<i>Koeleria macrantha</i>	13	15
northwestern sedge	<i>Carex concinnoides</i>	36	29
pinegrass	<i>Calamagrostis rubescens</i>	60	46
quackgrass	<i>Elymus repens</i>	<1	5
rough fescue	<i>Festuca campestris</i>	24	14
sedge	<i>Carex</i> sp.	<1	5
spreading needlegrass	<i>Achnatherum richardsonii</i>	18	17
stiff needlegrass	<i>Achnatherum occidentale</i>	6	4
Forbs			
arrowleaf balsamroot	<i>Balsamorhiza sagittata</i>	<1	<1
black medic	<i>Medicago lupulina</i>	<1	3
brown-eyed Susan	<i>Gaillardia aristata</i>	2	1
common dandelion	<i>Taraxacum officinale</i>	6	7
common harebell	<i>Campanula rotundifolia</i>	3	6
cut-leaved anemone	<i>Anemone multifida</i>	1	4
early blue violet	<i>Viola adunca</i>	9	9
field pussytoes	<i>Antennaria neglecta</i>	<1	<1
fireweed	<i>Epilobium angustifolium</i>	1	1
Holboell's rockcress	<i>Arabis holboellii</i>	1	1
leafy aster	<i>Aster laevis</i>	3	9
lemonweed	<i>Lithospermum ruderales</i>	1	1
nine-leaved desert-parsley	<i>Lomatium triternatum</i>	3	<1
nodding onion	<i>Allium cernuum</i>	8	1
old man's whiskers	<i>Geum triflorum</i>	3	<1
round-leaved alumroot	<i>Heuchera cylindrica</i>	1	1
short-beaked agoseris	<i>Agoseris glauca</i>	21	18
silky locoweed	<i>Oxytropis sericea</i>	1	1
slender hawksbeard	<i>Crepis atriobarba</i>	2	1
small-flowered blue-eyed Mary	<i>Collinsia parviflora</i>	1	<1
spikelike goldenrod	<i>Solidago spathulata</i>	15	19
Thompson's paintbrush	<i>Castilleja thompsonii</i>	1	1
timber milk-vetch	<i>Astragalus miser</i>	16	9
tufted phlox	<i>Phlox caespitosa</i>	10	0
umber pussytoes	<i>Antennaria umbrinella</i>	0	4
white pussytoes	<i>Antennaria microphylla</i>	9	1
wild strawberry	<i>Fragaria virginiana</i>	18	18
yarrow	<i>Achillea millefolium</i>	8	7
yellow penstemon	<i>Penstemon confertus</i>	21	13
yellow salsify	<i>Tragopogon dubius</i>	1	<1

Continued on next page

Common name	Scientific name	1999	2006
Trees and shrubs			
antelope-brush	<i>Purshia tridentata</i>	6	1
Douglas-fir	<i>Pseudotsuga menziesii</i>	7	1
kinnikinnick	<i>Arctostaphylos uva-ursi</i>	68	38
saskatoon	<i>Amelanchier alnifolia</i>	23	16
soopolallie	<i>Shepherdia canadensis</i>	1	<1
western snowberry	<i>Symphoricarpos occidentalis</i>	<1	1
Substrates			
Litter		99	98
Microbiotic crust		16	31
Rock		1	19
Soil		5	56

APPENDIX A2 Plant species frequency in 1999 (pre-treatment) and 2006 at the Douglas-fir site.

Common name	Scientific name	1999	2006
Grass and grasslike			
bluebunch wheatgrass	<i>Pseudoroegneria spicata</i>	2	5
common timothy	<i>Phleum pratense</i>		<1
Idaho fescue	<i>Festuca idahoensis</i>	1	1
junegrass	<i>Koeleria macrantha</i>	5	1
Kentucky bluegrass	<i>Poa pratensis</i>		<1
northwestern sedge	<i>Carex concinnoides</i>		16
pinegrass	<i>Calamagrostis rubescens</i>	65	59
quackgrass	<i>Elymus repens</i>		3
rough fescue	<i>Festuca campestris</i>	10	7
sedge	<i>Carex</i> sp.		3
spreading needlegrass	<i>Achnatherum richardsonii</i>		4
stiff needlegrass	<i>Achnatherum occidentale</i>	2	2
Forbs			
arrowleaf balsamroot	<i>Balsamorhiza sagittata</i>	8	6
black medic	<i>Medicago lupulina</i>		5
bull thistle	<i>Cirsium vulgare</i>		3
common dandelion	<i>Taraxacum officinale</i>	5	5
common harebell	<i>Campanula rotundifolia</i>		5
cut-leaved anemone	<i>Anemone multifida</i>		<1
diffuse phlox	<i>Phlox diffusa</i>		<1
early blue violet	<i>Viola adunca</i>	10	6
field chickweed	<i>Cerastium arvense</i>	1	4
field filago	<i>Filago arvensis</i>		<1
field pussytoes	<i>Antennaria neglecta</i>	8	8
heart-leaved arnica	<i>Arnica cordifolia</i>	6	
Hood's phlox	<i>Phlox hoodii</i>		<1
lemonweed	<i>Lithospermum ruderales</i>	1	4
narrow-leaved hawkweed	<i>Hieracium umbellatum</i>	2	12
nine-leaved desert-parsley	<i>Lomatium triternatum</i>	1	1
nodding onion	<i>Allium cernuum</i>	8	1
northern gentian	<i>Gentianella amarella</i>		<1
perennial sow-thistle	<i>Sonchus arvensis</i>		2
pulse milk-vetch	<i>Astragalus tenellus</i>	1	
purple-leaved willowherb	<i>Epilobium ciliatum</i>		3
Rocky Mountain butterweed	<i>Senecio streptanthifolius</i>	4	
Scouler's hawkweed	<i>Hieracium scouleri</i>	7	
short-beaked agoseris	<i>Agoseris glauca</i>	2	3
showy aster	<i>Aster conspicuus</i>	8	
slender hawksbeard	<i>Crepis atriobarba</i>	1	4
small-flowered blue-eyed Mary	<i>Collinsia parviflora</i>	4	1
smooth aster	<i>Aster laevis</i>	<1	17
spikelike goldenrod	<i>Solidago spathulata</i>	3	3
spreading dogbane	<i>Apocynum androsaemifolium</i>	7	9

Continued on next page

Common name	Scientific name	1999	2006
Forbs (continued)			
three-spot mariposa lily	<i>Calochortus apiculatus</i>		1
timber milk-vetch	<i>Astragalus miser</i>	3	2
tufted phlox	<i>Phlox caespitosa</i>	1	
white pussytoes	<i>Antennaria microphylla</i>	3	1
wild strawberry	<i>Fragaria virginiana</i>	8	14
yarrow	<i>Achillea millefolium</i>	9	10
yellow hedsarum	<i>Hedysarum sulphurescens</i>	4	4
yellow penstemon	<i>Penstemon confertus</i>	7	5
yellow salsify	<i>Tragopogon dubius</i>		1
Trees and shrubs			
antelope-brush	<i>Purshia tridentata</i>	3	2
baldhip rose	<i>Rosa gymnocarpa</i>		1
birch-leaved spirea	<i>Spiraea betulifolia</i>	31	28
Douglas-fir	<i>Pseudotsuga menziesii</i>	9	9
kinnikinnick	<i>Arctostaphylos uva-ursi</i>	36	24
prickly rose	<i>Rosa acicularis</i>	2	
Rocky Mountain juniper	<i>Juniperus scopulorum</i>		<1
saskatoon	<i>Amelanchier alnifolia</i>	12	10
soopolallie	<i>Shepherdia canadensis</i>	3	1
tall Oregon-grape	<i>Mahonia aquifolium</i>	1	1
Substrates			
Litter		98	100
Microbiotic crust		56	48
Rock		6	11
Soil		6	23